EFFICIENCY OF MANUFACTURING SYSTEMS

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EFFICIENCY OF MANUFACTURING SYSTEMS

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Published in cooperation with NATO Scientific Affairs Division

PLENUM PRESS · NEW YORK AND LONDON

Library of Congress Cataloging in Publication Data

NATO Advanced Research Institute on the Efficiency of Manufacturing Systems (1982: Amsterdam, Netherlands)
Efficiency of manufacturing systems.

(NATO conference series. II, Systems science; v. 14)
"Proceedings of the NATO Advanced Research Institute on the Efficiency of Manufacturing Systems, held September 6–10, 1982, in Amsterdam, The Netherlands"—Verso t.p.
Includes bibliographical references and index.
1. Production management—Congresses. I. Wilson, B. (Brian) II. Berg, Claus C. III. French, D. (Doug) VI. Title. V. Series.
TS155.A1N34 1982 658.5 83-2316
ISBN 0-306-41256-X

Proceedings of the NATO Advanced Research Institute on the Efficiency of Manufacturing Systems, held September 6–10, 1982, in Amsterdam, The Netherlands

A Division of Plenum Publishing Corporation
233 Spring Street, New York, N.Y. 10013

Printed in the United States of America

PREFACE

The Advanced Research Institute (A.R.I.) on "the efficiency of Manufacturing Systems" was held under the auspices of the NATO Special Programme Panel on Systems Science as a part of the NATO Science Committee's continuous effort to promote the advancement of science through international co-operation.

Advanced Research Institutes are organised for the purpose of bringing together experts in a particular field of interest to identify and make known the present state of knowledge in that area and, through informed debate, to make recommendations for directions for future research that would benefit the community at large. To this end two kinds of contribution were obtained by invitation. There were those papers which were about the current state of work in the area of manufacturing systems and its organisation; in addition three theme papers were presented to provide a stimulus to the discussion in terms of ways of thinking, both about the area and about the kind of research needed.

Discussions about the efficiency of manufacturing systems are particularly opportune given the present economic difficulties faced by many countries; and an ability to make improvements in this area is crucial to the long term recovery of many industries in this sector. The systems science panel took the view that concepts from the more general area of integrated production systems would be helpful in identifying how such an ability could be developed. In this context, integrated production means the extension of the control processes (associated with conversion of raw material into end products) beyond the hardware to include the decision-making processes of what may be termed, 'the management control systems' of the enterprise as a whole.

An organising committee was formed to prepare a programme and to design an appropriate structure within which the present state of knowledge could be presented and the applicability of the above concepts explored. This committee also assembled a group of participants from member countries representing the academic community and practitioners.

Twenty five participants from ten NATO countries contributed to the A.R.I. including those who served on the organising committee. Each participant played an active part and the success of the event was due entirely to their enthusiasm and effort. We thank them for their willingness to present the results of their work, to act as chairmen and/or rapporteurs and to participate so fully in the various sessions.

The A.R.I. was organised through two kinds of session: parallel workshops on specific areas of interest and plenary sessions in which papers were presented and workshop reports made and discussed.

The proceedings are structured in four parts. Part I presents an overview of the A.R.I. and describes the structure of the week together with summaries of the plenary expositions. The workshop reports are given in part II, and part III contains a summary of the final plenary discussion and some concluding remarks. Part IV contains the three theme papers together with the other papers which their authors presented briefly at the meeting.

Special thanks are due to Professor Hans Zimmerman and Professor Arthur Thomson who acted as rapporteurs for the whole of the workshop discussions and to Morley Sage who acted as secretary to the plenary sessions. It is their reports together with those of Professor Doug French and Professor Claus Berg, the workshop chairmen, that form the basis of this report from the organising committee. I am very grateful for the advice and help given by Professor Peter Checkland prior to and during the A.R.I. Thanks are also due to Miss Jeanette Davies and Miss Christine Gardner who dealt with the initial correspondence and circulation of papers and to Mrs. Susan Jarman who provided secretarial help at the meeting.

B. Wilson

CONTENTS

PART I

PART II

PART III

PART IV

PART I

1. OVERVIEW SUMMARY

2. STRUCTURE OF THE A.R.I.

3. SUMMARY OF PLENARY EXPOSITIONS

1. Overview Summary

In order to encourage a rich but hopefully well-structured discussion of the efficiency of manufacturing systems two decisions were taken which helped to shape the meeting.

Firstly, the concept "efficiency" was interpreted broadly. "Efficiency" can be taken to refer to the degree to which an explicit objective is achieved: a 100% efficient telephone system never fails to make the right connection. Also important, however, is that the objective is the right one - it is possible efficiently to achieve an objective which is then seen to be undesirable: the achievement is efficient but not effective. It was decided that both efficiency and effectiveness were the concern. In addition "manufacturing systems" (converting raw materials into a physical product) were taken to be a special case of "production systems" in which some input is transformed into an output of greater utility.

Secondly, in order to focus discussion, the three connected theme papers argued a particular position. This might be summarized as follows. There are many aids available for the design and operation of production systems; but many such systems are neither efficient nor effective. What is lacking is the effective bringing together within the enterprise of the elements which would comprise a production system well-integrated into the overall activity of the company or institution. The concept of "engineering" (in the broad sense of the term) an integrated production system is too little entertained, and methodology for the task is both too little known and too little developed.

Given this framework the theme papers asked and tentatively answered three questions:

(i) How can we conceptualise and think about the efficiency and effectiveness of production systems? Answer: by using systems thinking.

(ii) How can we research the establishment of integrated production systems? Answer: by doing action research in which collaborative effort between an enterprise and the researchers seeks to establish such a system in the given situation.

(iii) How can we seek to "engineer" integrated production systems? Answer: by using systems concepts in an explicit methodology.

The other papers briefly presented at the meeting, were considered in relation to this overall theme.

2. Structure of the A.R.I.

The organising committee assembled contributions in three main areas in addition to the theme papers. These areas were:

(a) Theory and mathematical tools related to manufacturing/production

(b) manufacturing/production systems themselves

(c) general considerations related to manufacturing/production activity

Equal weighting was given to each area and an average of six papers per area was obtained. All papers were made available prior to their presentation and this enabled some discussion of each paper to be held in plenary session following a brief presentation by each author. However it was intended by the organising committee that each group of papers together with the relevant theme paper should provide the major stimulus to group discussions in the parallel workshops.

Two workshops were formed; one concerned with the organisational implications of integrated production systems and the other concerned with information for control. It had been the intention to form a third workshop devoted to a discussion of human factors in production but it was argued, during the introductory session at the meeting, that human factors were so inextricably bound up with the concerns of the other workshops that it would be more valuable to explore the human related aspects of production within the other two workshops.

The first parallel workshop session followed the brief presentation of papers in groups (a) and (b) above and the full presentation of the first two theme papers. It was felt by the organising committee that more time for presentations and discussion should be allocated to the theme papers in order to make clear the nature of the proposition presented for discussion (as described earlier) and to ensure that discussion in the workshops would be directed towards the expected outcomes.

Although the area of concern of each workshop was different, the expected outcomes were the same. From the first parallel workshop session these were to be preliminary thoughts on:

(i) Concepts of particular importance

(ii) Apparent problems to be tackled

(iii) The appropriateness of action research

(iv) Consideration for the other workshop.

These were still to be discussed by the second set of parallel workshops but, as these would be preceded by the presentations from group (c) above and the third theme paper, the outcomes were extended to include:

(v) Methodology relevant to integrated production systems

(vi) Research needed

(vii) Educational needs

Workshop reports were made following both group sessions and a final plenary session was held to discuss the possible organisation of research in this topic. The overall structure of the week was thus that presented in Figure 1.

	MORNING	AFTERNOON	EVENING
MONDAY	PLENARY SESSION INTRODUCTION Theme Paper I plus 2 Papers (Group a)	PLENARY SESSION 5 Papers (Group a)	
TUESDAY	PLENARY SESSION Theme Paper II plus 3 Papers (Group b)	2 Papers (Group b) PARALLEL WORKSHOPS • Organisation Structures • Information for Control	PLENARY SESSION Workshop reporting
WEDNESDAY	PLENARY SESSION Theme Paper III plus 4 Papers (Group c)	2 Papers (Group c) PARALLEL WORKSHOP • Organisation Structures • Information for Control	WORKSHOP CONTINUED
THURSDAY	PLENARY SESSION Workshop Reporting	PLENARY SESSION International Organisation of action research & the dissemination of the generalised lessons learnt	PRODUCTION OF WORKSHOP AND FINAL SESSION REPORTS
FRIDAY	REPORT PREPARATION (ORGANISING COMMITTEE)		

Figure 1. Structure of the Advanced Research Institute--The Efficiency of Manufacturing Systems.

3. Summary of Plenary Expositions

This section is intended to capture the major messages contained in the papers presented. Although each theme paper was presented on different days with other papers interspersed, as mentioned earlier, they present a particular proposition and hence will be taken together in this summary.

The first paper, 'Systems concepts relevant to the problem of integrated production systems' by P.B. Checkland, addressed itself initially to the question 'what is an integrated production system?' This he answered by developing a simple model of any enterprise in which he represented five distinct kinds of system which must be present if the enterprise is to survive in its related environment. One of these, the transformation process (which may convert raw material into product or, at a higher level, may convert a perceived market need into the satisfaction of that need) he took to be representative of an integrated production system. He then went on to develop a set of concepts (human activity systems concepts) which can be used as a modelling language to describe real production/manufacturing systems through the many perceptions of them that exist in the minds of the managers in the situation.

The kind of research which has led to these particular concepts has been carried out over a number of years in collaboration with a variety of managers in a variety of organisations. It is known as 'action research' and this was described in the second theme paper; 'the nature of action research' by A. Warmington. The essential features of this approach to research are that significant collaboration is required between the researcher and the managers in the situation being studied and the necessity for an explicit conceptual framework in which to undertake the analysis. Given the existence of these features in a project it is possible to derive and implement changes to the situation that are regarded by the managers as improvements (the action) and to learn from the process of analysis that lead to the changes (the research). It was argued that to improve the effectiveness as well as the efficiency of manufacturing systems it is this kind of research that is appropriate.

In the third theme paper, 'Methodology related to integrated production systems' by B. Wilson the argument was mounted that by widening the boundary of the control systems to include the human decision-takers one is faced with a fundamentally different kind of system than the purely automatic control system. The boundary of this system containing hardware may be precisely defined but the boundary and nature of the

resultant management control system is a function of the multiple perceptions of the managers in the situation and is hence subject to many interpretations. The nature of the problems confronting the analyst in relation to an integrated production system were outlined and methodologies were presented (with actual examples of their application). These are particularly appropriate to the analysis of organisation structures and to the derivation of the information needs of an enterprise.

These three papers, together presented (1) concepts for thinking about integrated production systems, (2) ways of finding about them and (3) ways of using these concepts to bring about change.

The remaining papers presented in the plenary sessions can be divided into three separate groups with respect to each main area of interest:

Group 1: Theory and mathematical tools related to manufacturing/production

Group 2: Manufacturing/production systems themselves

Group 3: General consideration related to manufacturing/production activity.

The papers in group 1 were related to the use of engineering and mathematical concepts to the optimization or improvement of integrated manufacturing systems performance.

'A Cluster Algorithm for Process Layout' by D. French discussed the use of algorithmic approaches which can be applied to the application of computers for control of manufacturing. A general production flow algorithm was presented which enables management to establish a unified approach for product type layouts. There are three production flow stages which require analysis to determine the best layout for efficient manufacturing: Factory flow, Group and line analysis. French presented a single algorithm which can be applied repeatedly reducing the variety techniques to each production flow stage, and the problems of applying different techniques during the analysis stage.

'Mathematical Tools for Integrated Production Systems' by J.J. Solberg discussed a mathematical model which represents the

work flow through a manufacturing system as a queuing process. The can-q model fulfills the special requirements of system designers to have recommendations in the early stage of a design process, when basic decisions have to be made. The concept of Solberg laid stress upon the fact, that the description of the behaviour of manufacturing systems has to adopt an appropriate global strategy and tries to avoid the usual particle-level viewpoint.

'Analysis of Flexible Manufacturing Systems' by E. Canuto, G. Menga and G. Bruno discussed an approach to analysing and designing a Flexible Manufacturing System (FMS). A FMS must be designed to be able to meet changes in the environment and internal failures, yet still maintain a high utilisation of plant. Special changes in the environment considered are quantity and diversity of demand. An example of meeting internal failures is of graceful degradation, in case of failed machines. The system model presented considers free resources to be optimised, constrained resources and tasks of the enterprise. Several system control variables are then determined in a hierarchical problem solving process. The levels are the operation location, the part allocation, and the routing and scheduling.

'Simulation of Production Systems with DESFOR' by G. Bruno and E. Canuto presented a program package oriented to the simulation of discontinuous systems written in FORTRAN. The simulation approach follows the 'process view of simulation'. The feasibility of DESFOR was exemplified by the simulation of a flexible manufacturing system. The authors followed an interactive approach consisting of three software levels. At the bottom level of the model flow of parts through the system is simulated.

The middle level controls the execution of the schedule determined by the top level. The top level elaborates the scheduling of operations on machines, taking into account limited availability of fixtures and tools.

'Manufacturing Lead Times' by I.P. Tatsiopoulos discussed an approach which specifies that manufacturing lead times are dominated by transit times between operations. Empirical research findings show that about 90% of total flow time is due to transit time. The problem of estimating manufacturing lead time is seen as a problem of discovering the influencing factors. The most important factors being 'backlog of work in the shop' and 'capacity planning method'.

Special interest is concerned with the hierarchy of backlogs and lead times, which is formed by customer orders waiting for material, non-released shop orders, released shop orders and queues of items waiting for particular machine centres.

'A Classification Scheme for Master Production Scheduling' by J.C. Wortmann emphasised problems relating to Material Requirement Planning methods, and to Master Production Scheduling systems. MRP systems are inherently deterministic and are derived by explosion of customer orders or from forecast of requirements. MPS systems (which contain MRP as a sub-set) permit management to exert some influence over the planning function, and to control average lead time in manufacturing departments. As average lead time is a parameter in MRP the aim is to keep the work-load a constant, which in turn maintains an average lead time and utilisation, thus facilitating lead time management.

The papers in group 2 were using a general systems approach in design and improvement of performance of integrated production systems.

'On the Design and Monitoring of a Master Production Scheduling Function in a Manufacturing Resource Planning Environment' by J.W.M. Bertrand extends the concept of master production scheduling by introducing a further concept of control using the logistics approach within the framework of general control theory.

'Improving Manufacturing Efficiency with Better Logistical Control' by A. Waldraff and E. Zahn presented a case study on modelling the dynamic interaction of manufacturing output, sales volume and inventory levels for a company, emphasising that in their view the logistical (effectiveness) aspects appear to give a much higher gain margin for manufacturing systems than the procedural (efficiency) aspects. There had furthermore been a major problem to reconcile the model created with the notions of the personnel operating the system and four iterations had been required.

'Use of Group Technology Concepts in Integrated Production Planning' by I. Nisanci reviewed the concepts and problems in the use of group technology in the design of integrated production systems. It was emphasised that this approach will have more importance in the future when considering the use of CAD/CAM.

'Production Planning in a Small Firm in the Glass Industry' by O.B.G. Masden was not presented. However, the paper gave a description of production planning in the small firm.

The papers in group 3 were concerned with illustrating a commonality of problems throughout the world when considering integrated production systems.

'Problems in Formulating Production Planning in a Threshold Country' by I.A. Pappas examined the particular problems in a threshold country. The definition of a threshold country being one which, although not at the level of the advanced industrial countries of Western Europe and North America, has, nevertheless, made sufficient advances in manufacturing technology that it is no longer a developing country. Such a country has its own unique problems in that although manufacturing has advanced rapidly from the artisan stage the information collection and flow has not yet reached a stage where it can either make the company more efficient or keep up with the technological advances. Secondly the business and financial elements are reluctant to finance such businesses due to their historical relationships to the merchant system. Thirdly the background of the country can restrict the acceptance of new concepts due to the cultural aspects of the country and its more conventional educational systems. In some threshold countries language can also be a barrier and unless one of the "accepted" technical languages such as English, German or French is adopted, this could restrict growth as the language does not have the ability to define new technology.

'A Systems Approach used in defining Higher Management Information Needs in a Manufacturing Company - Principles and Methodology' by C. Kastrinakis discussed the four main categories in defining managerial information needs, the by-product techniques, the total study process, the null approach and the key factor methods. This paper was in contrast to the previous paper in that it was concerned with a project carried out with a large manufacturing company. It illustrated a problem encountered in many large companies that of having the means to collect and update data, but having to determine the needs and requirements of Higher Management to ensure that sufficient and correct information is obtained. The comparison of the papers by Pappas and Kastrinakis illustrates the gap which exists between the threshold and advanced technology countries. It is of interest to note that in both cases the dissemination and use of information appears to be one of the major problems in the use of new technology.

'Integrated design and Production Systems for Strategic Production' by A.R. Thomson illustrated the need for advanced technology, in different countries due to the average age of the populations. For example, the fact that more people in undeveloped countries are available for the job market whilst in developed countries the supply of labour is decreasing, leads to the necessity of better utilisation of existing manufacturing plants, and the introduction of new technology.

'Manufacturing Management: Effects on Productivity and Quality' by F.A. Alic and 'Automation in Perspective - An Overview' by D. Radell re-emphasised the previous concern of the inter-relationships between the advance in technology and the requirements of human factors in integrated manufacturing systems.

'Integration and the Definition of Responsibilities' by D.J. Rhodes, M. Wright and M.Q. Farell considered the problems of size and span of control when evolving from the owner-director type of small business to that of a large company, and considered the methodology required to arrive at this evaluation.

'Need Assessment - A Tool for improving Manufacturing System Design' by Knut Holt emphasised the problems in design by stating that managers, engineers and academics are good at solving problems but not at defining problems. In problem solving, engineers focus on the technical aspects, but the key elements in problem definition are needs, constraints, definition and priorities. Problem solving in which individual needs are both social and emotional must therefore consider both as an integral part of the solution process.

'Manufacturing Systems Research: Impressions of a Research Programme' by F.G. Waterlow described a research programme sponsored by the Science and Engineering Research Council in the U.K. which examines manufacturing as a systems concept. Some general conclusions from the research results of the programme as a whole were inferred, and suggestions on future research needed were made.

The summary has presented only the briefest indication of what the papers contain. It has been included to give the reader a feel for the range of topics discussed. However, part IV contains the papers, reproduced in full, and the reader is referred to that section in order to fully appreciate the valuable messages conveyed by each contribution.

PART II

4. WORKSHOP REPORTS

4.1. INFORMATION FOR CONTROL

4.2. ORGANISATION STRUCTURES

4. Workshop Reports

4.1. Information for Control

Chairman: Professor D. French
Rapporteur: Professor H. Zimmermann

The aim of the workshop was to attempt to identify areas and type of research needed arising from an examination of information for control as the boundary of the control system was extended to include the human decision-taking elements. The workshops met on two days and adopted two approaches to the discussions. The first meeting was concerned with a general wide-ranging discussion of the kinds of problems experienced in information systems, and on the second day, the discussion was structured around an examination of the process of designing an integrated production system, the concepts that were likely to be of use and the specific problems that were raised by this process.

General Discussion

The workshop discussed information flow under a number of headings:

(i) Defining information flow, its purpose, content and the needs of the user

(ii) The problems involved in processing data

(iii) The methods of gathering, processing and storing data

At the outset it was considered that a distinction should be made between data and information and it was agreed that whereas data is the raw accumulation of outputs from a machine, process or system, information is the meaningful interpretation of this data so that action can be taken. The purpose of an information flow system was to support the activities of the organisation (rather than the desires of particular managers within that organisation) and was essentially used for controlling or evaluating the effectiveness of the production/manufacturing system. It is apparent, within this widened interpretation of a manufacturing system, that information is required at different levels, from corporate level to the workshop level. However,the type and amount of data will vary with each particular function within the manufacturing structure and should be derived with particular reference to the particular needs of that function.

It is frequently the case that the higher level information needs are seen as no more than an aggregation of the needs of the lower levels and are hence generated as a by-product of the lower level operational systems.

A thorough discussion within the workshop indicated that a major problem with the flow of information was that of the amount and type of data. It was emphasised that a computer printout, for example, frequently contained far too much data to be assimilated and analysed by an individual for it to become the useful information necesary to make the decisions required of that individual.

It was considered that too much data was a result of:

a) Poor selection and filtering of data due to imprecise specification of requirements

b) reluctance on the part of users to abandon data that has been regularly provided but that has ceased to be useful

c) the mistaken impression that more data means better decisions

d) the desire to receive additional data relevant to other areas of the organisation to enhance the status and power of the individual manager.

Too little data was seen mainly to be due to:

e) non-communication between individuals in the company

f) the poor definition of areas of decision-taking

g) a reluctance on the part of some managers to generate data for the benefit of others that they themselves, did not need.

The question of integrity and validity of data was also discussed and was seen to be affected by two considerations:

(i) Data which is correct but is inappropriate for the application

(ii) Data which is appropriate for the application but is incorrect.

Data in both of these categories is used and whereas (ii) is a function of the data processing (i.e. capture, storage, processing, accessing and presentation), (i) is a function of the way requirements are specified. Both (i) and (ii) may occur together, and the results of the presence of either (i) or (ii) is considerable reduction in the effectiveness of the production/ manufacturing system. Hence it is crucial for the effective operation of any organisation that methodology is derived and used to enable the correct specification of its information (and hence data) requirements.

A further factor affecting (i) above is the timeliness of the data. Again problems here (essentially of updating) may be due to any of the data processing elements mentioned above. However, they may also be due to poor reporting methods, the fact that individuals may be unable to keep within the time frame of the system requirements within their own area of responsibility and the inability of the data flow to keep pace with the dynamics of the system.

DISCUSSION RELATED TO TYPE OF MANUFACTURING SITUATION

Further discussion was centred around the kind of manufacturing situation from which the data for control was generated and in which it could be used. The group agreed that different types of manufacturing are conceivable, each with advantages and disadvantages, with different types of requirements and limitations. Three such types were defined as examples and used as a framework for the discussion. It was felt that the decision about the desirability of the different types would have to be made on a higher level, e.g., social, political level, which was beyond the scope of the meeting.

The three types of manufacturing systems were defined as:

(a) The automatic factory, characterised as flexible manufacturing, e.g. a system which by CAD/CAM automates the control of the manufacturing system to the highest degree possible. The interface with the management control system would be data-channels from aggregate planning and areas neighbouring manufacturing such as: receiving, accounting, sales, etc.

(b) Semi-automatic Manufacuturing

For this system the tasks would be assigned to machines or human beings according to "who does it best".

(c) A People-oriented Manufacturing System

This type of system focuses on the capabilities and needs of human beings in performing productive or control functions. The boundary to neighbouring sub-systems could be drawn differently to 1. above. The characteristics with respect to information would not change drastically by a variation of boundary.

The results of the discussion can be summarised according to the following matrix:

Type of manufacturing / Aspect	Automatic Factory	Semi-Automatic Factory	Human Oriented Factory
Effect of the nature of Management Control Systems	i	iv	vii
Means of Information capture, storage processing and transmission	ii	v	viii
Purposes of Information	iii	vi	ix

The numbers in this matrix refer to the paragraph numbers which now follow.

i. The information system would have to include the following functions:

Data capture
Data storage
Data interpretation and manipulation
Activation

The effects of the nature of Management Control Systems would be least here because information technology can at present accommodate almost all conceivable needs of Management Control Systems.

ii. Three problem areas could be defined

(a) in the capture of data: there are still areas where automatic (quality) control is at present not possible (technological research needed)
(b) automatic systems cannot make non-predesigned judgments (particularly important in stochastic environments).
(c) there are control problems which because of their complexity can still be solved better by human heuristics and control behaviours (for instance using fuzzy sets as modelling language) to enable automatic control devices to do their jobs.

iii. Purposes of information in this and the other cases are:

a) Planning and control of process/machine; and systems performance
b) Statutory and reporting requirements

vi. See (vii).

v. Here primarily the different capabilities of human beings and EDP equipment would have to be taken into consideration. While people are, for instance, much better in making judgments EDP is much more efficient in processing high volumes of information. On the other hand the limitations of humans with respect to information reception - as outlined under viii, would have to be considered for all information processing assigned to people.

vi. Purposes as in iii plus performance of management.

vii. & viii.

The information system in this case serves primarily people and not machines. Therefore aspects such as values, meanings, etc., have to be considered in the design of the system.

In particular the limited capability and willingness of people to 'digest' large amounts of information per time unit has to be taken into consideration. This means for example:

a) decisions on whether on-line or batch processing is appropriate.

b) use of appropriate communication language.

c) design of the system as hierarchical and selective with optional detailed back-up information.

d) user oriented design.

e) more support in complicated information processing (optimisation) should be rendered to the user.

f) formatting and display has to be adapted to human capabilities.

g) the definition of the role of a manager has to be defined such that he can process all the information per time unit necessary to fulfil his function.

h) measures of performance and effectiveness of the system have to be included.

i) ergonomic requirements have to be recognised.

j) the purpose here is to inform the manager in an appropriate way to plan, control and monitor the performance of machines, systems and management.

ix. Here the major problems in the specification of purpose for the information to be supplied, are the multiple perceptions of the managers concerned. It is in this area that the concepts of human activity systems and the methodologies relevant to integrated production systems have the most to offer.

It was felt that primarily research of the classical type is needed for cases (i-iii) even though some Action Research (Theme paper 2 - The nature of Action research) might be helpful and needed in capturing human intelligence (Artificial Intelligence, heuristics) without which the automata would not be able to control the system effectively.

For cases (iv-ix) the strongest argument could be made for the use of Action Research and its use should be encouraged. This is particularly advisable because in these cases strong interdisciplinary research in "soft science areas" is needed.

DISCUSSION RELATED TO CONCEPTUAL DESIGN

In looking at the conceptual design process the three types of manufacturing situation previously defined were reduced to two considerations: an orientation towards human operated control systems and an orientation towards automated control systems. The conceptual design process was derived and was seen to consist of the following seven stages:

(a) Define the boundary of the integrated production system, including an agreed definition of its purpose

(b) Establish the set of activities necessary to achieve the above purpose but within the defined boundary

(c) Define their interconnections in terms of:
material flow
information flow (operational and performance monitoring)
decision relationships (control actions)

(d) Group activities to form realisable management roles

(e) Define measures of performance appropriate to each role

(f) From b, c, & e, determine the information requirements essential for the management of the integrated production system through the roles defined in d.

(g) Design the data processing procedures needed to achieve the above (f) information requirements (i.e. data capture, storage, procesing, accessing, presentation and frequency).

It was agreed that, irrespective of the orientation defined initially, this design process was applicable. It specifies <u>what</u> has to be done, the only difference between the two orientations was in terms of <u>how</u> it was done.

Given a people orientation, the particular concepts that were applicable to stages a - c were those related to human activity systems (Theme paper 1. - System concepts relevant to the problem of integrated production systems). The root definition specifies both the purpose and the boundary of the integrated production system and the conceptual model (primary task) provides the basis for stages b and c.

Given a machine orientation the boundary can be expanded until the control problems become a function of the particular characteristics of the human decision-taker, i.e. requiring judgment or the use of unknown heuristics.

In doing stage d, the useful concepts are those derived from organisational theory in terms of responsibility definitions and job satisfaction but also those described as systems overlay methods (see Theme paper 3. - 'Methodology related to integrated production systems').

Concepts of capability, orientation, potentiality and utility applied to an analysis in terms of human activity systems were agreed to be relevant to stage e and primary task analysis and the maltese cross (Theme paper 3.) were seen to be useful tools in relation to stage f.

Considerable literature and experience exists relevant to stage g and this was not discussed further, it being argued that appropriate requirements specification resulting from the application of the relevant concepts to stages a to f was the most important in recognising areas for further research.

Methods of research

In discussing how research might be undertaken to improve the above design process a definition of the boundary of an integrated production system was considered. An agreed version of the process of achieving integration was:

The bringing together of that set of activities which are under the control of the chief executive of an enterprise.

Given this broad definition what are the considerations and what are the appropriate research methods? The discussions can be summarised as follows:

(i) There is still considerable scope for research of all kinds for improving the efficiency and effectiveness of manufacturing systems. Traditional research is appropriate when the considerations are related to the technology but action research is the most appropriate when the considerations are in terms of the relationship between the social system and the technology.

(ii) The specific type of research is necessarily dependent upon a number of features:

a) The increasing use of high technology

b) The rapid advances in the use of high technology equipment

c) The specific problems of emerging and threshold countries

d) The behaviour of human operators and the relationship to system effectiveness

e) Communication problems, both multi-national and multi-disciplinary.

(iii) The bringing together of both scientific and action oriented research is necessary to ensure that the existing (and the rapidly increasing) state of technology is used to the full to achieve both efficiency and effectiveness within the framework of existing situations or in the design of semi or fully automated manufacturing systems.

4.2 Organisation structures

Chairman: Professor C. C. Berg
Rapporteur: Professor A. R. Thomson

The aim of the workshop was to explore the organisational and structural implications of creating integrated production systems. The workshop met on two days, first for a wide ranging discussion of the area then for an exploration of the problems associated with the structural/organisational design of an integrated production system. The ultimate intention was to define the research needed (and the kind of research needed) if production systems are to be not only efficient as semi-autonomous entities but also contributing as effectively as possible to the overall task of a productive enterprise.

This condensed report covers the general discussion of the concept integrated production system, and is then structured thus:

Concepts
Problems
Relevance of Action Research
Research Needed

General Discussion

There was a general acceptance of the need for both efficiency and effectiveness in production systems; and general agreement that the latter requirement calls for careful organisational linking between the production system and the rest of the enterprise of which it was a part.

Crucial elements relevant to an integrated production system were thought to be:

- properly engineered links with all aspects of product exploitation other than making it, which is of course the responsibility of the production system itself;

- a well-shared understanding by all concerned, workers and management, of the role of the production system in the enterprise;

- recognition that information is a major resource so that much attention is given to the 'knowledge' aspects of the production system as well as to its physical tasks;

- well-structured decision roles concerning both local autonomy and overall dominance by the needs of the enterprise;

- a high degree of automation and process sensing to monitor system performance; hence a high use of computers;

- flexibility so that adaptation to external changes can be rapid;

- robustness so that the system can sustain significant shocks without disintegration.

(i) Concepts

Much discussion tried to assemble the concepts relevant to the structural and organisational design problem.

Discussion centred on the concept 'integration' and the many potential ways of achieving it:

- Integration by information flow

  - vertical within a function
  - horizontal between functions
  - problems of information relevance
  - problems of the time horizon of information
  - problems associated with information for goal achievement versus information
  - problems of ad hoc -v- formalised information flows

- Integration by task allocation

  - integration could be taken to be a design task through the rational analysis and allocation of tasks

- Integration by controllability

  - definition of a control hierarchy, from physical control to the human decision - making control systems, could provide a route to integration

- Integration by authority

  - definition of a power structure as a source of integration

It was accepted that the organisational design task is immeasurably more complex than the design task of the

professional engineer. A number of design principles were discussed, it being generally accepted that design principles, not designs, were the only realistic target, given the unique nature of each situation involving human beings. Design principles suggested included:

- A rejection of the idea that there might be one best way to integration suitable to all production situations.
- A conscious search for a balance between sub system autonomy (of the production system) and system dominance (of the enterprise).
- A use of activity modelling (as developed in Checkland's Soft Systems Methodology) could help define tasks and structures and their inter relations.
- System robustness must be a prime aim.
- Attention to the culture of the enterprise is essential; design requires consideration of more than logical considerations, and will best involve the active participation of those who will be affected by the results of the design activity.

(ii) Problems

Obviously there are many problems of elaborating and using the concepts listed above; but the workshop decided to concentrate its attention on problems related to industrial production and to education and research activity relevant to industry. Problems suggested as significant included:

- Functional specialisation leading to poor communication and understanding between professionals of different kinds.
- The sub optimisation which frequently occurs because attention is focussed too narrowly.
- The problems of satisfactory interfaces between different functions or sub-functions.
- Poor adaptability to changes in markets or technology so that changes to operations, strategy and stuctures are innappropriate or too late.

- Low acceptability of desirable changes due to deficiencies of education or training.
- Lack of time for managers to think creatively about innovations as well as coping with day-to-day events.
- Related to this time lack is the problem created by the non availability of simple, well-understood methodology for the creation of integrated production systems.

(iii) Relevance of Action Research

The considerations listed above convinced the workshop of the virtues of research which would be actively engaged in the creation of integrated production systems rather than studying the problem from outside as if it were part of Nature. Such research clearly has to be team research employing people from different disciplines and with different functional responsibilities. This brings the work up against all the known problems of action research in social science - for example the problem of reconciling the needs of the organisation with those of the academic researcher. (Notably such research by combined teams was successful under the pressures of war!)

In principle the kind of action research discussed at this meeting - essentially 'traditional' action research but based on an explicit prior-stated framework derived from the newer developments in systems thinking - could bridge the industry/university gap. The general feeling in the discussion was that such an approach did provide a basis for further work.

(iv) Research Needed

Given the speculative nature of work in this area, which is struggling for conceptualisation rather than tackling well-defined problems within an established paradigm, it was agreed that two kinds of research were needed at this stage

Firstly useful findings would come from examination of previous research on production systems, both on their technical and on their human and management aspects, in order to tease out in more detail the significant features of future research which from its initiation would consider together both aspects as inseparable elements in any integrated system.

The existence of findings from this type of work would form a useful input to the second kind of research thought desirable, research on integrated production design carried out in an

action mode with industrial partners. If both kinds of research were planned together then the first would have the objective of establishing common definitions and conceptualisations which would underpin research of the second kind. The first type of research could usefully include appraisal of structures and modes of operation of existing production systems closely integrated into company operations as a whole (such as the technology dictates in an industry like paper-making). The hope and intention here would be to try to separate general characteristics from specific ones unique to a particular situation.

An important further goal of the first phase research would be to present a picture of the usefulness of research into combined technical and organisational features of production systems which could help to sustain an international network of researchers and managers anxious to improve the efficiency and effectiveness of their operations.

The eventual outcome from the total programme would be tested methodology for creating integrated production systems, methodology transferable from one situation to another.

In summary, the workshop felt that such (systems-based) methodology: does not currently exist; is needed; and might be developed through action research in a programme of the kind described.

PART III

5. FINAL PLENARY DISCUSSION AND CONCLUSIONS

5. Final Plenary Discussion and Conclusions

The aim of the final session was to bring together the major issues raised during the week; particularly those associated with areas of research, type and organisation of such research and implications for education. Many such issues had been aired during the course of formal discussions as well as in informal debate over coffee and lunch. This section attempts to bring these ideas together into a few broad areas of research which are regarded as key areas in the process of developing (and learning about) integrated production systems.

'Action research', as an appropriate mode of enquiry, had been a continuing topic during the week. Much discussion had focussed on its interpretation and its differences from traditional scientific research. It is worth recording this distinction.

In traditional research the researcher is external to the object of enquiry and the research does not affect the nature of that object, (i.e. research into the laws of magnetism does not change them). In action research the researcher is involved in the situation being researched and, by being involved, changes it.

Research into integrated production systems in which the boundary of investigation contains human decision-takers is of the latter kind and hence will resemble action research. Two features of action research are essential and must be explored prior to any such investigation.

(i) The degree of involvement of the researcher must be as high as possible given the nature and constraints of the actual situation.

(ii) An appropriate conceptual framework must be established and agreed at the start by all participating in the research.

The crucial nature of (ii) above was emphasised during the final session and it was agreed that action research must be supported if real progress is to be made in the derivation of usable concepts and methodologies for the development of integrated production systems.

Unlike traditional research in which a single project can establish transferable knowledge, the generalisations from action research can only be extracted with confidence from a

series of projects. An intervention which is successful in one company may turn out not to be transferable to another company, although that company may be regarded as similar.
The culture, politics, history and inter-personal relations are always unique features of any organisation. Thus, it is usually the case in action research that it is not the nature of the intervention that is transferable but the conceptual framework and the process of enquiry that led to the intervention. Learning of this kind can only come from a series of experiences rather than a single project. The implication of this is that the learning (and the dissemination of that learning) is much more difficult to organise, particularly if the action research programme is international. A research project to establish how such a programme could be initiated and maintained should receive some priority.

More specifically, if the design of integrated production systems containing people is to become a practical proposition then research is needed into the development of generalised activity models (primary task models) for specific kinds of manufacturing organisations. In relation to the improvement of existing organisations through more integration it is the sensitivity, in terms of effectiveness and efficiency, related to the choice of boundary of the I.P.S. which requires investigation.

One suggestion, which was generally supported, was that there are a number of integrated production systems in existence and a retrospective appraisal, using appropriate conceptual frameworks, would represent a valuable area of research.

There is already a substantial amount of the more traditional research into concepts and tools related to F.M.S. (flexible manufacturing systems), C.A.D. (computer aided design) and C.A.M. (computer aided manufacture) as well as the development of planning and scheduling tools (M.R.P. etc.) and this needs to continue. Technology exists and is continually being developed which takes integrated production/manufacturing systems towards the automated factory. Particular research which it was felt would aid this development was in the area of extending machine capabilities in terms of data capture, processing, aggregating and presenting data. In making the decisions about moving towards people-oriented or machine-oriented production/manufacturing systems it is the respective capabilities which need to be assessed. For example, the human decision-taker can make judgments but cannot process high volume, high density data. The need exists, if moves are to be made in the direction of the automated factory to undertake research into heuristics and human operator behaviour.

Such research is underway and will continue to attract support. The more difficult-to-specify action research, (difficult, in the sense that the researcher cannot predict what will be learnt), is not so well recognised. The initial proposition that was put to the A.R.I. was well supported and hence there is an urgent need to find ways in which an internationally supported, action research programme, aimed at improving both the effectiveness and the efficiency of manufacturing systems, can be established.

PART IV

6. INTRODUCTION

7. PAPERS PRESENTED

6. Introduction

During the course of the meeting, as discussion gradually began to focus on ideas and issues which most participants felt important, a classification of the papers different to that anticipated emerged. This new way of looking at the contributions seems helpful in trying to perceive the discussions as a whole.

It has been argued by Checkland* that it is useful to distinguish between systems of three types: Type 1 are systems dominated by the regularities of the universe - these are the systems investigated by the natural scientist. Type 2 systems are dominated not by Nature but by the logic of situations. The world of purposeful human action contains many such systems: for example the flows of materials and information which constitute the optimum use of resources in an engineering job shop. Finally, Type 3 systems - perhaps the most prevalent kind in the human world - are dominated by the meanings which autonomous observers attribute to what they observe, as when, for example, a prison is perceived by different observers as a punishment system, a rehabilitation system, an education system or a system to protect society.

Using this perspective it was suggested that the papers at the meeting fell into two categories. Some were concerned with the logic or purposeful production. The papers by Bertrand, Bruno, Canuto, French, Nisanci, Radell, Solberg, Waldraff and Wortmann were addressed to this aspect. The other papers, those by Alic, Checkland, Holt, Kastrinakis, Madsen, Pappas, Rhodes, Tatsiopoulos, Thomson, Waterlow and Wilson, concerned not so much the logic of production situations as the linking of logic-dominated production activity with broader systems in which different actors perceive the world differently. The ""engineering" of integrated production systems in the real world will necessarily entail the accommodation of systems of Type 3 with those of Type 2.

In the terms of this analysis, then, the meeting can be seen as a discussion of the issue that improved efficiency and effectiveness of production (including manufacturing) systems entails neither 'logic considerations' alone nor 'meaning considerations' alone but a complex combination of the two. There was broad agreement that bringing about this combination necessarily entails collaborative work between researchers and managers and that useful systemic concepts and methodology are beginning to emerge.

* P.B. Checkland Rethinking a Systems Approach Journal of Applied Systems Analysis 8 1981.

7. PAPERS PRESENTED

SYSTEMS CONCEPTS RELEVANT TO THE PROBLEM OF INTEGRATED PRODUCTION SYSTEMS

P. B. Checkland

Professor of Systems

University of Lancaster

The title of this paper is carefully worded, and is important. Its concern is not with the many individual problems of integrated production systems (IPS); to state it in that way would imply taking the concept of IPS as a given, and then concentrating on such matters as purchasing, efficient scheduling, inventory and queueing problems, computer control of production processes etc. Rather, this paper is concerned with the problem of the concept IPS itself, and how it may be used. Its core argument is that if we are concerned to increase the efficiency of production systems (of which manufacturing systems are a subset), then the concept IPS is relevant to that end; and that explicit use of systems ideas aids thinking about this problem area and leads to the adoption of a particular approach, both conceptually and in real-world action to improve production systems.

This paper, then, discusses the notion "IPS" and the systems thinking which has to be brought to bear to make use of the idea in practice. In the second 'theme paper'[1], Alan Warmington discusses the kind of work necessary to create and improve integrated production systems, namely "action research"; finally Brian Wilson in the third theme paper[2] develops methodology built upon the concepts discussed in the first two.

THE EFFICIENCY OF PRODUCTION SYSTEMS

Formulating the Problem

It was normal in Western society as recently as twenty years ago to elevate economic measures of performance above all others. Such was the commitment to the view of industrial society as a wealth-generating machine which would forever increase living

standards that to show that something was "uneconomic" was to end all argument about whether or not it should be done. In the 1980s world recession and a greater awareness of environmental issues has significantly changed that. It cannot be taken for granted that to increase the efficiency of production systems is undoubtedly to achieve a useful end. It is necessary to argue a position on the matter.

There are two reasons why in this paper I shall assume that increasing productive efficiency is desirable.

Firstly it is exceptionally difficult to continue to use an inefficient technical means once a more efficient one has been discovered. It is inconceivable that long and tedious calculations will continue to be done on hand calculating machines once computers are available which can be programmed to do them in seconds - just as the invention of calculating machines itself inevitably replaces much slow work with pencil and paper. Hence, even though it might be argued that all the industrial societies now need inefficient labour-intensive technologies in order to provide work for their unemployed millions, it is politically inconceivable that developed countries might agree not to pursue technological efficiency. Programmable robots, working consistently and never making trouble over tea breaks, will replace human workers (a) because such robots are technically possible and (b) because high-level political agreement not to use them could not be obtained. In that sense we are all hustled along by technological determinism, and society will have to learn to solve the problem of leisure rather than the problem of how to be technologically inefficient.

Secondly, a dispassionate look at the kind of work and work situation which industrial societies provide suggests that such employment does not often provide rich possibilities for the full development of human talents, individual and social. Much industrial work, especially in manufacturing, requires human beings to simulate robots, and deserves the cliché description frequently applied to it: "soul-destroying". This paper will assume that a search for more efficient production systems, which on the whole will mean automated ones, is desirable; the concomitant problem of leisure is assumed a "better" problem for our society to have to tackle.

Efficiency and Effectiveness

In speaking of the problem of the "efficiency" of production systems we refer specifically to the means of achieving an end, and assume that we need to reduce the amount of resources (materials, energy, human effort, information, time) needed to achieve it. But a broader consideration is also appropriate. There is not much achieved overall if we reduce the amount of resources needed to

reach an end which is itself undesirable! Our concern is more properly both with the efficiency of a production system and with its effectiveness, this latter consideration referring to the desirability of the system's end or objectives, where the former refers to achieving those objectives. This paper will assume that our concern is both efficiency and effectiveness. It is the inclusion of the latter consideration, especially, which makes certain systems concepts appropriate ideas for tackling the problem.

THE CONCEPT 'INTEGRATED PRODUCTION SYSTEM'

Assuming that the phrase "manufacturing system" applies to an organised set of processes in which some physical raw materials are transformed into a product of greater value[3], then all such systems are special cases of "production systems" in which any input (which could be abstract or concrete) is transformed into an output of higher utility[4]. In this sense,banks and insurance companies as well as carpet makers operate production systems; in the latter case the production system happens to include a manufacturing system in which there is physical transformation of textile and other materials.

Since the systems ideas which are the subject of this paper apply to production systems of all kinds (and hence to all manufacturing systems) it will use the former phrase. But this is not to say that there are ready-made, agreed, well-understood concepts of either "production systems" or "manufacturing systems", as the literature indicates[3 4 5].

It is instructive to examine the relatively unchanging literature of this area over the last twenty years. The three books cited serve as useful examples. In a book very typical of the mid-sixties Elmaghraby[4] argues that production processes have to be conceptualised as systems, using a distinctive "systems engineering approach". But although the introductory section states that

> It is becoming evident to industrial managers, for example, that the manufacturing interval cannot be reduced unless efforts to reduce it are coordinated, in a systemwise sense, with the activities of sales, accounting, engineering, and materials ordering (Reference 4, Page 2)

the focus of the book is not on the wider systemic coordination but on the fact that "the frontiers of the area" are "decisions which are subject to logical and quantitative analysis". Most of the book concentrates upon the operational system and its quantitative modelling.

The two later examples similarly indicate the interdependency between production and other functions within the organisation, but

themselves concentrate upon the production system as an entity. Thus Wild writes:

> ... the production manager must seek to influence this policy decision making since otherwise he may be required ... to pursue objectives, to provide outputs and to satisfy demands which because of the nature of the system cannot be achieved or can only be achieved inefficiently (Reference 5, Page 19).

In the language of the present paper this is an indication that system effectiveness is at least as important as system efficiency, though Wild's book itself is concerned with the latter rather than the former.

This is not to criticise these authors for doing what they set out to do, namely focus on the production system as an entity to be managed. Rather it is to indicate that the current frontiers of the subject, the areas in which research is needed are especially those concerned with integrating the production system into the enterprise as a whole. In systems language: much knowledge and many techniques are available to help ensure the efficiency of a production system as a sub-system of the enterprise which is its parent system. Much less is known about how to ensure that this sub-system contributes as well as possible to the overall performance of the system of which it is a part. In any systems analysis there is always a tension between "sub-system autonomy" and "system dominance"[6], since systems and sub-systems are by definition at once autonomous and subject to system or wider-system demands. In the case of production (and hence manufacturing) systems, both the literature and recent personal experiences in carrying out systems studies in manufacturing organisations suggests that more attention now needs to be paid to system dominance (and hence to mechanisms for integration) than to sub-system autonomy.

In summary, a concern to improve the efficiency and effectiveness of production systems implies a need for conceptualising an enterprise as a system one of whose sub-systems is the production function. It would be useful, therefore, to develop a rather general systems model of an enterprise as a means of conceptualising any production system as an integral part of the enterprise as a whole[7].

An Enterprise as a System

We may take an enterprise to be a relatively autonomous entity which organises various resources (abstract and physical) in linked activities which constitute a purposeful whole. The purposes pursued by an enterprise will be differently interpreted by different people, and the purposes themselves will change over time, but in order to constitute what we intuitively recognise as "an enterprise" there

must be continuous organisation and reorganisation of activities with some purposes in view.

The core of an enterprise we may describe as a transformation system (T) which transforms some input into some output. In the general case this can be termed the production system of the enterprise. It will express what Merton[8] calls the "manifest function" of the enterprise, what Rice[9] calls its "primary task", the task which an organisation is "created to perform". For a manufacturing firm it could be expressed materially as the transformation of raw materials into manufactured product, or in abstract terms as a transformation of market need into a satisfied need. Since the transformation process is being taken to be a purposeful system, it will itself have to contain a control sub-system (C_t) (Figure 1) which will monitor the processes of T and take action if they are not in line with requirements according to some selected measures of performance.

The system T will be carrying out a transformation by undertaking various activities. But because these are purposeful activities, they will not be random: T will be executing plans.

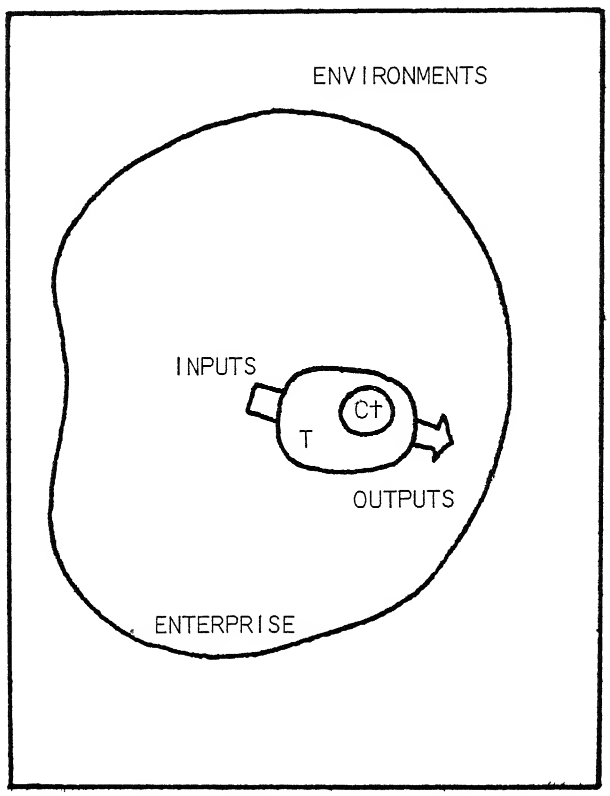

Figure 1: The Enterprise Model: Stage 1

Hence, linked to T must be a planning system P, which, being itself a purposeful system, will contain its own control sub-system, Cp (Figure 2). P is an enabling system without which T could not function: T needs its plans. Similarly, there will have to be another support system, call it S, which supplies T with appropriate resources - human, material, financial. It will have its own control system Cs.

Because the enterprise is an open system, exchanging goods, money, energy and information with its environment, it will need to be linked to its various technical, social and commercial environments. There will have to be a linking system L (with its control system Cl) (Figure 3).

Finally, because the enterprise is a whole entity reacting as a whole, there will have to be an enterprise-wide control system C which monitors and controls the whole system via links with the other control sub-systems. C for example will, among other things, ensure that sub-system P adequately plans the provision of resources by sub-system S. This enterprise control system will itself contain

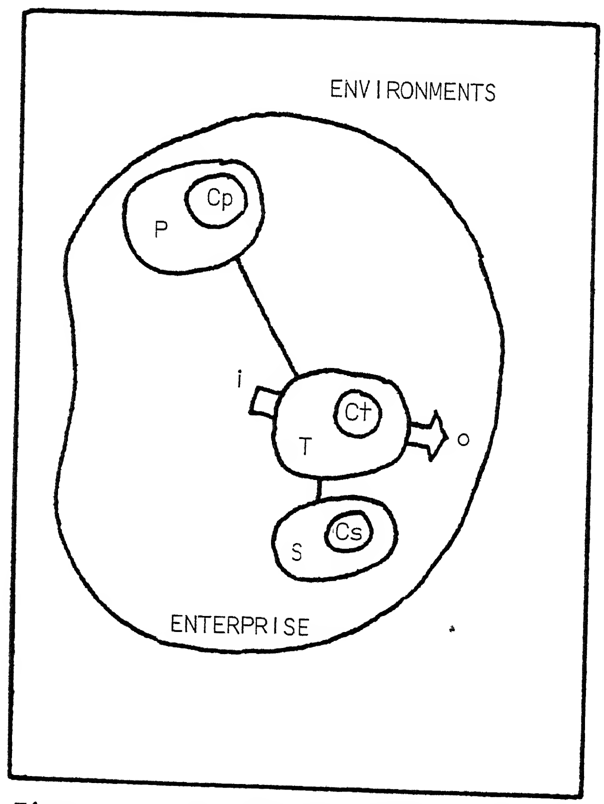

Figure 2: The Enterprise Model: Stage 2

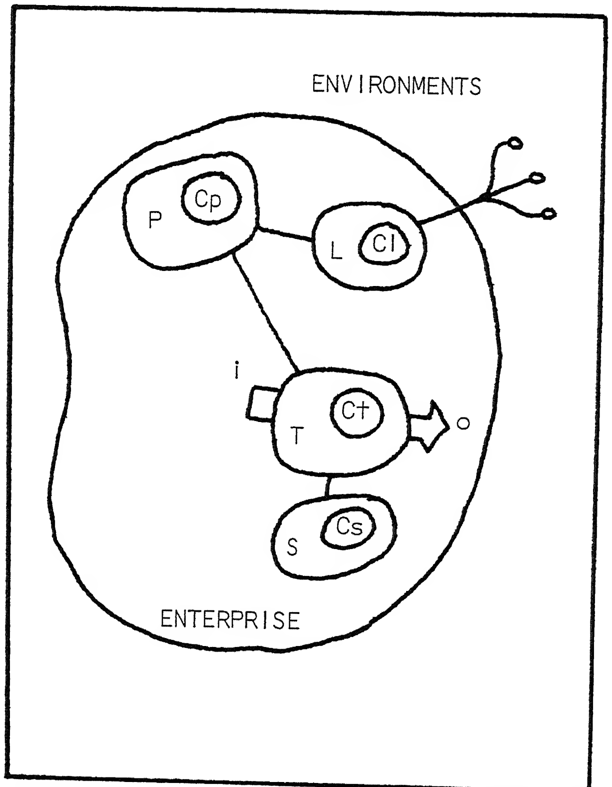

Figure 3: The Enterprise Model: Stage 3

its own control system Cc in order that its activities may adapt on the basis of environment changes or operational lessons learned (Figure 4).

Figure 4 thus represents an abstract model of activity requirements in an enterprise which can purposefully operate a transformation process and adapt and learn through time. Such activity requirements will be a source of the definition of the required information flows which feed or are generated by the activity systems. The words used to describe this simple model have deliberately avoided the names of common functions in real-world enterprises. In any real-world manifestation of Figure 4 the logical requirements there set out could be translated into many different functional structures:

L might include an R and D and/or a Marketing Department and/or a Legal Department;

T might be a Production Department;

S might include a Purchasing Department and/or a Finance Department and/or a Management Services Department;

C might be done by Corporate Planners etc.etc.

The selection of departments and their boundaries in real-world organisation structures are less fundamental than the components of the systems model of Figure 4: the former can be arranged in many ways as long as they embody the latter.

What then, in terms of this model, is an IPS? It is any real-world manifestation of T, together with the links by means of which it becomes an integral part of the whole enterprise. Note that the connectivity of the model is such that working with the concept IPS could lead into any other part of the enterprise. Research on IPS is research on the bringing together of the elements T and the connections between it and other sub-systems.

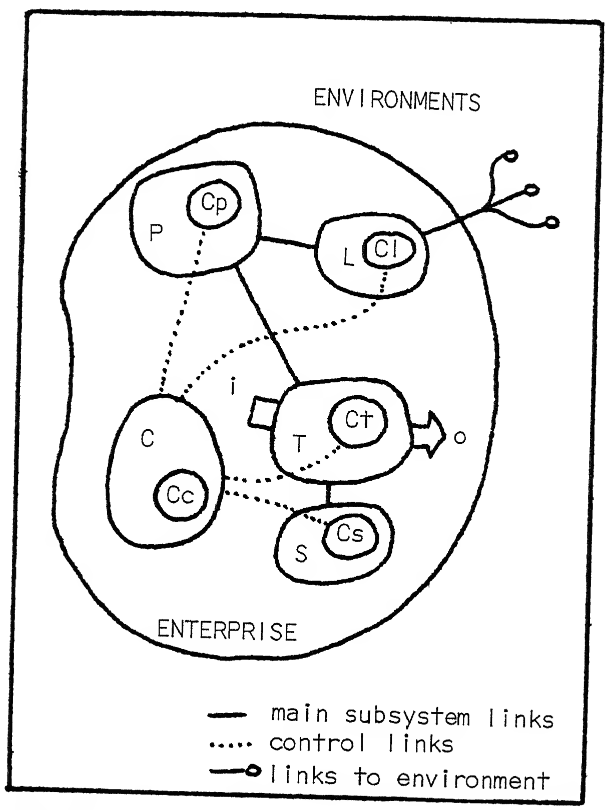

Figure 4: The Enterprise Model: Complete

BASIC SYSTEMS THINKING

The model of Figure 4 represents a way of conceptualising the problem of increasing the efficiency and effectiveness of production systems. It is now the problem of "engineering" (in the broad sense of that word) T and its links with P, L, S and C so that T pursues the most appropriate objectives as efficiently as possible. Largely this will resolve itself into an engineering of the necessary information flows.

In order to go about that "engineering" - something to be discussed in the third theme paper of this meeting[2] - it is important to appreciate the nature of the sub-systems of the enterprise model. In order to do this it is necessary to give a basic outline of recent thinking and research in this area. (What follows in this section is an extremely sparse account of systems thinking which is discussed and illustrated at length and in depth in Reference 10).

The Systems Movement

In the early years of this century it seemed to a school of biologists whose interest was in the living organism as a whole, the "organismic biologists", that the reductionism of physics and chemistry was probably not the most appropriate way to study an organism as an entity. The ideas concerning "wholeness" which they developed were eventually generalised to refer to wholes of any kind. For the last forty years there has been a conscious "systems movement" of people in many different disciplines interested in pursuing these ideas.

Because systems thinking is a meta-discipline which can be applied within any area of knowledge, the field is a complex one. Systems books are to be found in every section of university libraries! However, if we make the four distinctions set out in Figure 5 it is possible to compile a 'map' which can be used to understand any example of systems work. This map is also shown in Figure 5 with some examples of systems work which fall squarely within one area or another of the map.

In the terms of Figure 5, work on improving the efficiency and effectiveness of production systems will fall within area 3.2, while drawing upon area 3.1. To be more specific requires exposition of some further basic systems thinking.

A Systems Typology

The four crucial systems ideas form two pairs:

emergence and hierarchy
communication and control.

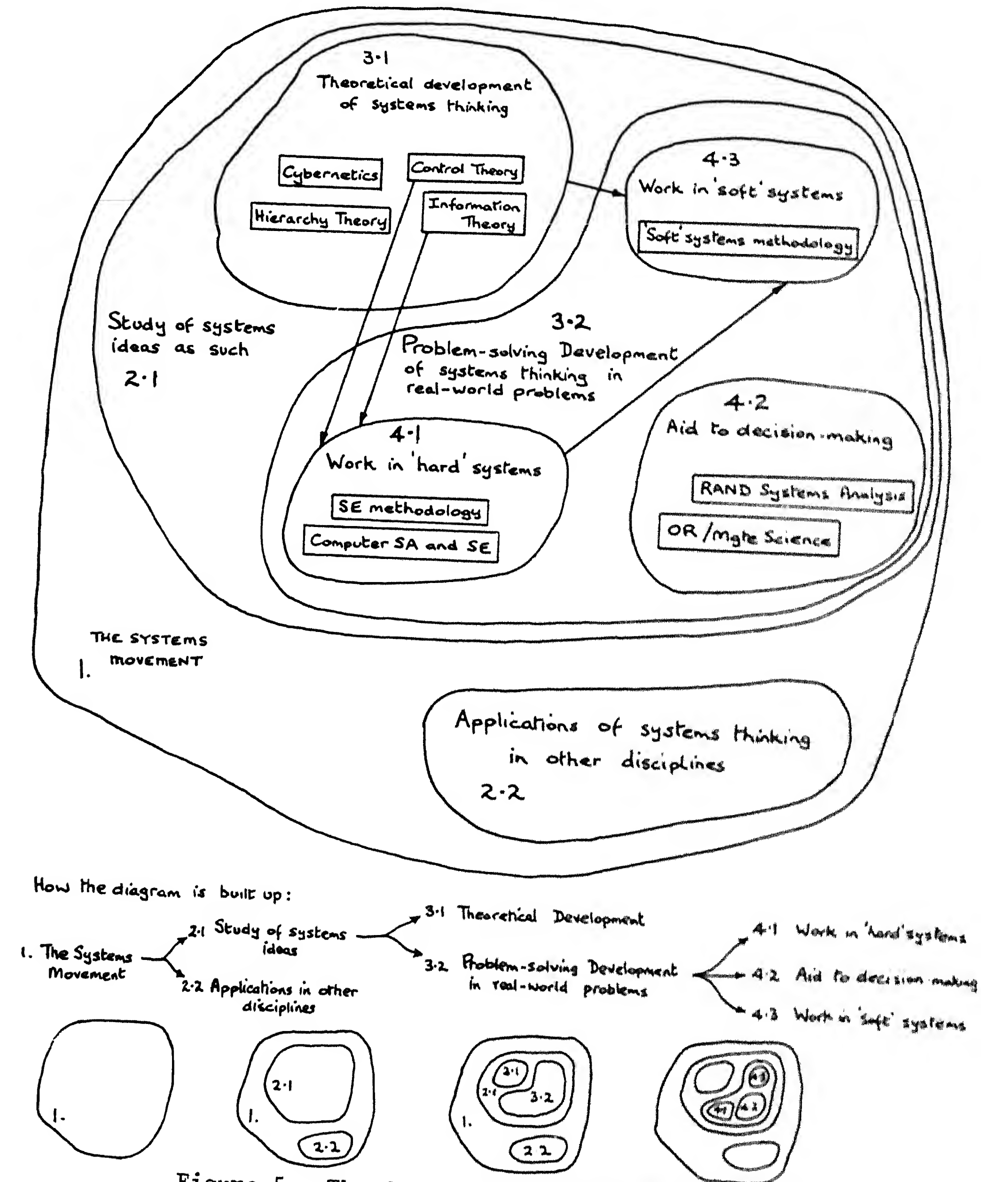

Figure 5: The Shape of the Systems Movement
(arrows show major influences)

The most important single systems idea is that of emergence, the notion that there are wholes exhibiting properties (so-called "emergent properties") which are meaningful only in terms of the whole, not its parts. To describe someone as "an explorer" is to name an emergent property of this particular personality. The taste of water is an emergent property of that substance; it has no meaning in terms of the hydrogen and oxygen which are the components of water molecules.

Taking the four ideas together, we may baldly state the systems metaphor: the universe contains certain wholes which reveal emergent properties; such wholes are hierarchially ordered, with autonomous wholes themselves being components of higher-level wholes; such wholes may survive in a changing environment (within limits) by taking control action (in the control engineers' sense), such action depending upon the availability of communication between the parts of the whole and between the whole and its environments.

Such a model brings us to the next question: what types of whole can be observed (or, more strictly, what ideal types of whole can be defined and then mapped onto real-world wholes)?

Systemically, the world may be described in terms of four types of whole (or "system"):[10,11]

natural systems (for which trees, frogs, man, the biosphere all provide illustrations)
designed physical systems (hammers, fire engines, computers)
designed abstract systems (mathematics, philosophies)
human activity systems.

The last type here embodies the notion that a set of human activities, linked together so that the whole constitutes purposeful activity, can be taken to be a system.

This would seem to be the system type most relevant to improving real-world production systems. Such systems may well contain designed physical systems in the shape of, say, manufacturing equipment, but the essence of improving their efficiency and effectiveness will lie in "engineering" the human activity which makes use of the equipment in the best interests of the system as a whole - itself best regarded as a human activity system.

Human Activity Systems

Using the concept of a human activity system requires a prior recognition of one of their intriguing and problematical aspects.

In the case of natural and designed physical systems, it will be possible to produce systems descriptions which can be publicly tested. A description of a frog, a bicycle or a nitric acid plant can be checked by any observer who cares to do so. All observers acting in good faith will agree that my bicycle has two wheels and a broken front brake. But human activity systems are not usually described in ways which are publicly testable. They are described by attributing meaning to them. The real-world human activity which I see as a terrorism system you may regard as a freedom-fighting system. There will, for example, be no single publicly-checkable account of a prison as a human activity system, even though there

would be agreement that a prison is constituted by a linked set of activities so that the whole is purposeful. But what kind of purposeful whole? An education system? A punishment system? A system to protect society? Any answer selected could be valid _within the framework of a particular way of perceiving the world_, within a particular _Weltanschauung_. In order to name a human activity system we have also to declare the _Weltanschauung_ which makes that particular name meaningful.

In the research programme in which these ideas were developed, we learned to name human activity systems very carefully in what we have called root definitions[12]. The basis of three possible root definitions of a prison is given in the preceding paragraph: education; punishment; protection.

In an example taken from Reference 10, a root definition relevant to work on patents, copyright and licensing in a science-based manufacturing company was formulated around the legal concept of "intellectual property":

> A professionally-manned system concerned with the overall management of 'intellectual property' so that by this management the system makes the best possible contribution to the business success of a science-based company.

(This embodies a _Weltanschauung_ that the company is operating in a world in which respect for the law concerning intellectual property makes this a resource which can be commercially exploited.)

The value of root definitions is that they enable conceptual models of the activity systems named to be built. The resulting models may then be compared with real-world activity so that the differences can feed debate about possible changes; or the models can be used as source of the defined information flows necessary for the purposeful activity to take place.

The conceptual model building itself consists of assembling the minimum necessary set of verbs which describe the activities required by the root definition. The aim is to achieve a defensible _pairing_ of root definition (what the system _is_) and conceptual model (what the system _does_) such that every activity stated or implied in the root definition is present in the model, and every activity in the model can be justified by reference to the root definition. The set of verbs is then structured according to the requirements of logic - "obtain raw materials" must precede "transform raw materials" - to yield the model. It is a good general rule to build a complete model with not more than about 6 - 12 activities. Each individual activity can then become the source of a new root definition and conceptual model at a more detailed level if required. Figure 6 shows the initial 8-activity model from the root definition given above.

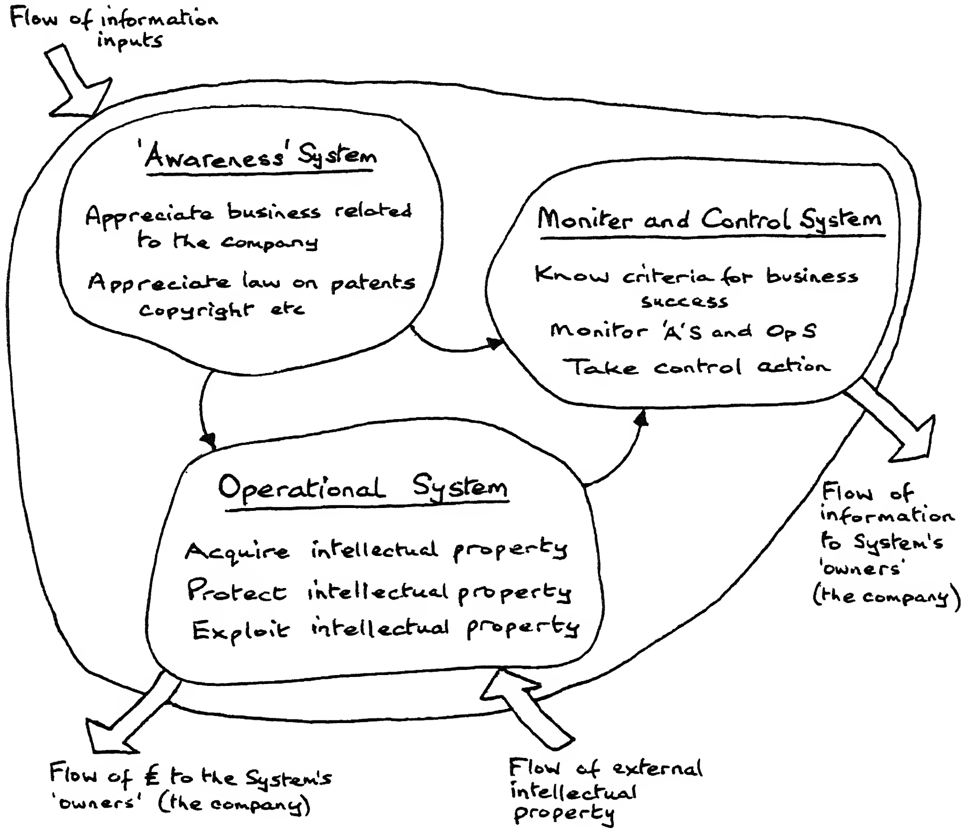

Figure 6: The "Intellectual Property" System: initial 8-activity version

Issue-based and Primary Task Root Definitions

In recent years research using these concepts in real-world problem situations has revealed a distinction which it is helpful to bear in mind in selecting the systems to model. It is a distinction likely to be important in work on integrated production systems, that between root definitions which are "issue-based" and those which express "primary tasks"[13]. The former express systems which relate to organisational issues and are not usually mappable onto any real-world organisation entities; examples might be "a system to decide warehouse policy" or "a system to ensure the survival of Management Services Department". Primary task root definitions, on the other hand, try to express the nature of an organisational entity as a human activity system in as neutral a way as possible, in a way which excludes as much attributed meaning as possible. For example, a primary task root definition of a prison would eschew the meanings previously discussed (education; punishment; protection) and base itself, perhaps, on the concept of accepting, storing and despatching people designated "prisoners".

It is usually the case in real-world problem situations that an issue-based analysis is essential in the initial stages in order to appreciate the perceptions of those in the problem situation. Later, primary task models may be sought as a step towards defining the more-or-less permanent information flows necessary if a sub-system such as a production system is to be properly integrated into the enterprise as a whole.

RESEARCHING IPS: ACTION RESEARCH

In any real-world organisation its manufacturing and/or production system will be a particular embodiment of sub-system T in Figure 4. But how the other sub-systems are organisationally manifest, and how T is linked to P, S, L and C, will be decided within the perceptions of significant actors in the organisation. These may be rational perceptions, or they may be the result of history, power struggles and personality clashes. Usually they will be the result of a complex changing mix of these factors. What is certain is that each real-world production and manufacturing system will have features unique to it. Since research on IPS is research on <u>the bringing together</u> of the elements T and its links elsewhere, such work needs to become involved in the real-world practice of particular organisations. The best way to research such systems with a view to increasing their effectiveness and efficiency is to try and create them in specific situations, hopefully later generalising from a sequence of such projects.

Such research - "action research" - is the subject of the second theme paper at this meeting[1].

CONCLUSION

In summary this paper has argued:

- that a concern for the efficiency of manufacturing systems is part of a broader concern for the efficiency and effectiveness of production systems;
- that improvements in efficiency and effectiveness of production systems can be sought by seeking to "engineer" IPS;
- that systems thinking provides concepts relevant to "engineering" such systems;
- that the crucial concept is that of the human activity system;
- that issue-based followed by primary task analysis can provide a route to the engineered information flows necessary to sustain an efficient and effective IPS;

- that appropriate research in this area needs to be "action research" concerned with creating an IPS in a specific context.

The following two theme papers carry this argument further, examining respectively the nature of action research and methodology which uses the systems concepts presented here.

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THE NATURE OF ACTION RESEARCH

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I suppose my task in writing this paper is not only to outline the nature of action research but to open a discussion on how relevant the ideas of action research may be to the subject matter of the Conference. This I will attempt towards the end. I should however first make it plain that I write as a social scientist influenced particularly by the concept of the open socio-technical system first enunciated by The Tavistock Institute in U.K. At the time of writing my very limited knowledge of integrated production systems leaves me slightly doubtful how well the approaches to management problems of the systems analyst or systems engineer, and the social scientist, fit together.

Nevertheless, the potential of action research is being increasingly recognised in social science approaches to management. It accords well with some of the new methodological ideas in the social sciences. It permits the researcher by his involvement in action to get a much deeper understanding of the inter-relationships, the patterns of behaviour and the springs of behaviour in organisations and other complex social systems than he could do through orthodox observation and hypothesis testing. An interest in systems pre-supposes an interest in the relationships between sub-systems - relationships that can be best understood in action. So, prima facie, there should be a considerable amount in this approach too for those researching into manufacturing systems as systems.

What then do we mean by Action Research? R. N. Rapoport[1] has given the most widely accepted definition which I have paraphrased

elsewhere as follows:

> Research which aims to contribute both to practical concerns of people (including people in organisations) and to the goals of science, via joint collaboration within a mutually acceptable ethical framework.
>
> It is characterised by:
>
> 1) The immediacy of the researcher's involvement in action;
>
> 2) The intention of both parties to be involved in change.

It will be seen that a number of facets not usually associated with scientific research are emphasised in this definition. First of all the practical ends of the research, which are given precedence over the scientific goals of the researcher; secondly the fact of joint collaboration (usually with members of the organisation itself who are probably equal partners to the research process); third a shared framework of values - an aspect of research which is likely to be emphasised particularly by social scientists whose training tends to sensitise them to the ethical consequences of their involvement in change. Then there is the fact of change being the foal of research, and particularly the requirement that the researcher himself gets involved in action - meaning usually that he takes part in the planning and inplementation of whatever proposals are made, monitors them and accepts some measure of the responsibility for their effects. This last I believe to be crucial.

There is an important aspect of action research mission from this definition of Rapoport's. This is the need for the action researcher to enter into the research with a clear and adequate conceptual or theoretical framework, which he applies to the research. some things done in the name of action research in the past seem to have lacked this essential ingredient and the reputation of the approach may have suffered thereby.

It is obvious from this definition that action research has a very different basis from logical processes of discovery that natural scientists claim to be the basis of the positive method. In fact it breaches a number of the tenets of theoretical positive science: for instance that data should be independent of the observer; that the data and the research process should be mutually independent; and that experimental conditions should be controlled. The problem in studying organisational processes has always been that these conditions are rarely attainable. The processes of any one organisation or one social situation tend to be unique; facilities for controlled experimentation are rarely available; the observer, by his very presence, almost inevitably becomes an actor; causation

is exceptionally complex and interactive, and it becomes invalid to attempt to break down phenomena into simple parts or sub-processes. Economists, psychologists and sociologists - as well as systems analysts in the Checkland mould - have attempted to deal with these problems in a number of ways. The phenomenological approach to discovery[2], for instance, suggests that in many situations it is not appropriate to formulate preliminary hypotheses and set about testing them, but rather to make a careful systematic examination of the nature of the problem as seen from various perspectives, and to work through observation, and particularly through observing from the inside the processes of change and development, and then to interpret the findings in such a way as to get a deep "insider's" understanding of the system and its behaviour. Many pieces of action research, though not by any means all, start from this kind of approach to scientific discovery.

In my own view the theoretical basis of an action research programme is very important. But is is most unlikely that such a programme can be successfully established on the basis of a single functional discipline such as industrial psychology or operations research or industrial engineering or production control. Effective action research usually requires an inter-disciplinary approach within an "eclectic" or "holistic" framework. This makes it even more important that the analytical framework is adequate and that the action researcher himself is continually critical of his model and seeking to improve it. The objective of the research programme is not to advance any particular discipline but to improve understanding within the organisation in a real sense, and add to our general knowledge of organisations as systems.

The third way in which the action research process departs from more orthodox approaches - and a main reason why it seems so useful - is that it induces the parties involved in the research to learn from the changes with which the research is concerned. It is from the involvement of the researcher with other parties in analysis, planning and action, that much of the learning from the action research process arises - learning, as we shall see, both about the particular situation being researched into, and also about some of the general characteristics of systems undergoing change. This idea is well summed up in the title of a well known American article of the 1950's: "Studying and creating change: a means to understand social organisation".[3]

Interestingly this last point constitutes one of the areas in which action research also differs from orthodox consultancy. Consultants also (hopefully) enter an organisation with a fairly clear conceptual framework and they work in collaboration with members of the organisation to make recommendations for improvement. Where the action researcher takes the process significantly further is in this very fact of staying with the organisation during detailed

implementation of the changes, monitoring those changes and in particular attempting to gain further understanding as a result of his close involvement with the system as it reacts.

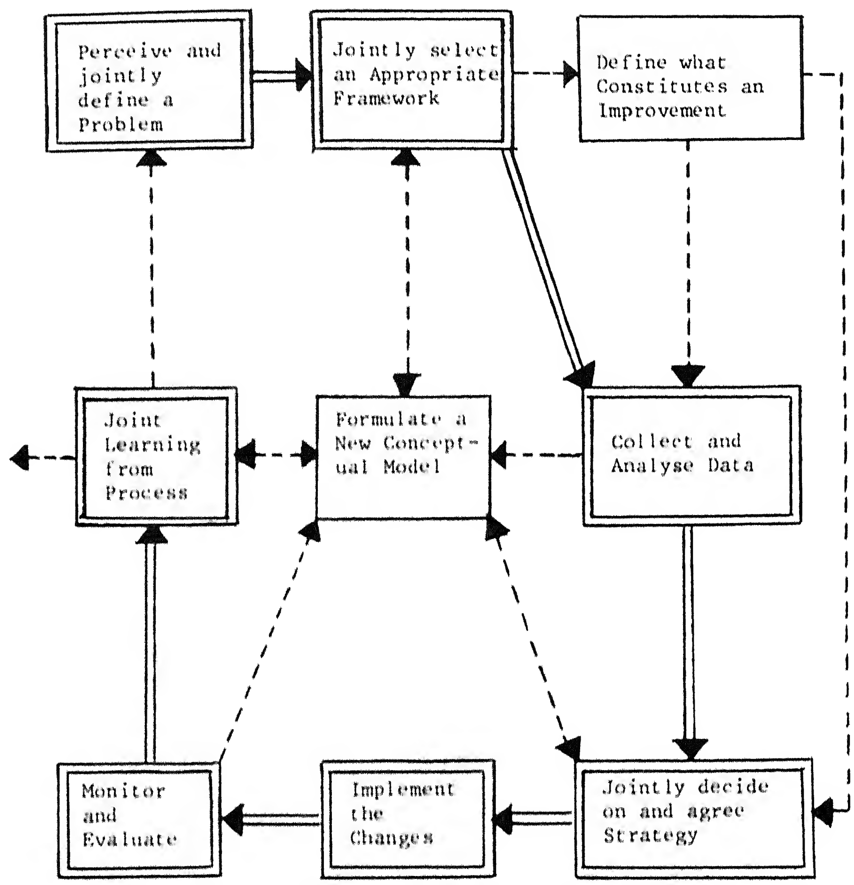
Now to look at the detailed steps of the action research process. I should like to put forward the following model which we can use to discuss the various stages. I think it makes fairly explicit much of what we have said up to now.

At the top left hand corner of the diagram we have a problem or a situation that required improvement (as distinct from say a phenomenon raising an intellectual conundrum, as may occur in a laboratory situation). It is at this point that joint collaboration begins; for both parties need to discuss the problem and come to some common agreement about its relevance, its nature and indeed its definition. Neither the client nor the researcher can unilaterally define for the other the subject of the research. This process of joint exploration indeed is the beginning of discovery leading to wider understanding.

We have said a number of things about the second box already. The conceptual framework must be such as to allow the research to deal adequately with what has now been defined as an organisational problem, and now as an exercise in any particular discipline. Thus a social scientist may well find himself needing to appreciate some of the physics, the chemistry, or the process engineering aspects of the production system and the costs and accounting considerations; while the engineer will necessarily get involved in such factors as the structure of authority, system of rewards, attitudes and perceptions and the nature of conflicts existing, in the situation he is examining. This of course creates problems, some of which we will touch on later.

The interdisciplinary nature of the action research approach necessarily complicates the collection and analysis of data - the third box. It also helps to point up some of the difficulties and strains likely to occur between the various parties collaborating in a programme of action research. People working together from different disciplines are likely to have different perspectives on the problem, the appropriate framework to tackle it, and the kind of data needed to analyse it properly. Further, as many of us know, there are considerable differences in value between the academic research culture on one hand, and managerial cultures on the other, which have to be coped with.

Now, as a result of problem formulation, discussions about the appropriate analytical framework, and the collection and analysis of appropriate data, new light may well be thrown on the nature of the original problem. These first stages in the action research process tend therefore to be iterative. The new insights may lead to the



MODEL: The Action Research Process

formulation of a new conceptual model of the situation, the possible modification of the original theoretical framework, the need to collect new data in the light of this new framework, and perhaps to analyse it rather differently; and so yet again the problem may appear in a different light. Already therefore through the collaborative processes of definition, model formulation, data collection, and further discussion, an increasingly sophisticated understanding is being formed of the nature of the organisation, or the nature of the particular situation being investigated.

However, action research by its nature has to go beyond this, and it requires some proposals for change to be formulated, discussed, and eventually implemented. Therefore, following the collaborative processes represented by the first three boxes in the diagram, both the conceptual framework and the increasing understanding have to be used by the parties as the basis on which to formulate some kind of a strategy for change - change, it must be emphasised, that arises out of the analysis. In our own research, we discovered that, because of the risks necessarily involved in making large changes, this usually evolved best as a step by step strategy, each step being implemented separately and its effects monitored before the next step was taken.[4] So once again there is interaction: this time between the three boxes labelled strateby, implementation, monitoring, and also, rather importantly, between those boxes and the conceptual model, since monitoring and evaluating the effects of change can itself modify the parties' understanding of the way the whole system is operating.

To emphasise this point yet again: much of the learning about organisational behaviour takes place as a result of feedback from the changes the research has brought about. For this reason the action researcher has to stay within the organisation throughout the whole process of investigation and working out the detailed strategy for change, and of implementing and monitoring that change. The understanding and learning that then comes about is always the result of collaboration and prolonged discussion.

One further point about the diagram. The arrows from the final box, labelled "joint learning", go off in various directions. First, as a result of the whole process the original situation - the problem which needed solving - is better understood and hopefully this new understanding will lead to improved behaviour in future. Secondly, the conceptual model of the system is modified and improved. Thirdly the world of learning, the world of science should be advanced as a result of successful research.

This leads us to consider the nature of this wider learning that arises from action research. We need to do this with some care. An implication is often made that "research" should be done in pursuit of generalisable new "truths" or with the aim of making additions to

the corpus of scientific laws. The learning resulting from action research on the other hand tends to be contingent on the nature of the organisation in which the research has taken place. Can it, then, really be termed "research"?

Let us look back at the action research process. In undertaking action research we study problems occurring in a specific organisation; but we do so in the light of one or more general theoretical frameworks - general models of (for instance) the causation of behaviour in systems. Action research gives us an opportunity to develop on the ground new analytical tools and new conceptual frameworks, and to test the appropriateness or the usefulness of these tools and frameworks in real settings. So a programme of action research can enable us to develop and modify, and to test the usefulness of a particular approach.

Moreover, by examining a specific organisation under-going changes, we may be able to get a better understanding of the circumstances in which certain types of behaviour are generated, certain efficiences are obtained, certain problem situations are likely to arise, and certain patterns of relationships are likely to be formed.

Again, action research is usually undertaken on the clear assumption that patterns of causation will be complex and that the behaviour that takes place in a given situation can only be understood if the research makes a detailed examination of that situation in all its complexity. Thus the research project is likely to result in an understanding of the general nature of complexity, and it may help us to develop better methods to tackle and understand it.

To sum up, an action research project should in the first place yield learning that can be directly relevant to the problems of the particular organisation, and useful to its members; but it should also help social scientists develop tools and techniques for analysing complex systems, and improve our general understanding of organisational behaviour. It can deepen our knowledge of the complex interactions that take place in organisational settings. Action research has however relatively little to contribute to more abstract generalised ideas and would rarely provide prescriptions that could immediately be applied to other situations than the one being researched.

We have said that action research is normally a collaborative process, where collaboration takes place between the action researcher and , usually, managers of the organisation being studied. We have however failed to say much about the action researcher himself. His role is a rather unusual one. The orthodox term "research" often has the implication of individual responsibility for, or hierarchical organisation of, research design, procedure,

interpretation of results, and so on. Such a researcher has specialised knowledge and a disciplinary skill which enables him to make decisions about the processes of the research and the criteria by which it should be evaluated.

Action research demands something quite different. According to most authorities there are a number of more or less equal parties to the research[5], and so there are considerable ambiguities in the researcher's role. He is at different times a collaborator, an advocate, and expert on method, an educator. And yet both he and his managerial colleagues are often exploring what they all admit to be unknown territory, and having to work out methods as they proceed. The action researcher has to maintain close, fully integrated, relations with his colleagues, often in conditions of some stress. And yet he does have a special role and his own knowledge and skills must force him from time to time to stand apart either as a mentor or at least as a specialist in particular aspects of the research design. Further, his intellectual approach must also be a widely based one and he must be able to select with confidence from a variety of research frameworks so as to help construct useful and appropriate models of the situation being analysed, and get these accepted. One of the most important skills of the action researcher - a skill not emphasised in research training - is the ability to cope with role ambiguity.[6]

One of the controversies in this area is what formal status the researcher should hold in relation to the organisation being studied and to any academic institution associated with the research. The three broad categories into which the action researcher usually fits are: the internal consultant formally employed by the organisation; a member of the academic world or of a research institution who is able to establish a close association with a client organisation over an extended period; and a professional consultant or member of a consulting organisation closely involved over a long period with the client. Each category has advantages and each has disadvantages.

The obvious advantages of the commercial consultant are in personal freedom and independence from the more subtle pressures imposed by members of the client organisation. A member of a large consultancy firm may also have the ability to call on a considerable range of resources of skill and expertise. However, the commercial consultant, or any commercial organisation, is bound by commercial considerations, and has to demonstrate short-term success to present and future clients. Commercial organisations can rarely devote the time and effort necessary to convert a consultancy contract into one of genuine action research.

The external researcher working from an academic base does not have these pressures on him. He is probably able to supplement his

own skill and knowledge by tapping other academic resources, and he can use his independent base to help support his professional values and to counteract organisational pressures. However, academia tends to reward "research results" rather than practical involvement. The researcher from academica needs to be committed to the "action" element in action research. The particular advantages of the outside researcher are in his professional independence and orientation towards the longer term. His main disadvantage may be in gaining acceptance from colleagues from within the organisation and in getting into the organisational culture which forms the context for the research.[7]

The internal consultant employed by the organisation to undertake action research, has the opposite kind of problems. He may have succeeded to his role from a number of different backgrounds, or he may have been appointed directly from outside the organisation. He may have transferred to that position from another managerial or technical role within the organisation. He is likely to have a good knowledge of organisational processes and expected attitudes and behaviour in the organisation. However, if he has "grown up" inside the organisation he may find it more difficult than a newcomer to identify the idiosyncrasies of his own culture. He also has a problem in getting his work seen as a legitimate and obtaining credence from his own colleagues for the unorthodox role he is performing.[8] More important, he may be dependent for resources and facilities on some of the dominant elements in the organisation and may need to achieve success according to criteria laid down by the established power structure. He does not have an independent "home base" like the professional consultant or the academic researcher and may have to rely on information networks of relationships (especially relationships with other change agents in other organisations) for the kind of intellectual and moral support that this role requires.

We may seem to have overstressed the peculiarities and conflicts in the action research role. However, a number of writers have emphasised the dilemmas and conflicts which have to be dealt with if the action research process is to succeed in its objectives.[9] Unfortunately there is no time to elaborate on these in this paper.

The final topic is to do with the applicability of action research. The approach has tended to use models which stress the systems nature of organisational phenomena. The areas to which it has typically been applied are in the social and behavioural sciences and in particular to means of improving efficiency via organisational change and development, redesign of authority structures, or examining means of improving job satisfaction and the quality of working life. However, there could almost certainly be wider applications in many areas of business science. Projects in which the writer has been involved include organisational design in continuous process

plants and aspects of engineering design, work flow and production scheduling. Action research has been used elsewhere in the development of management information systems and in investigating systems effectiveness. Action research seems most applicable where the situations being investigated are complex and where a systems approach is relevant - as indeed is the case in many features of organisational research.

Perhaps the main constraint on the applicability of action research is the implication that change has to be a consequence of, an inevitable part of, the process. Where change is involved, systems ideas (and indeed socio-technical systems ideas) are certainly accepted as relevant tools for analysis.

I started the paper by confessing my almost complete ignorance of the details of systems engineering or of integrated production systems and manufacturing systems. This being so I think it is for those expert in these areas to discuss the applicability of the kind of approaches outlined above to their problems, rather than for this writer to intrude further into that discussion.

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METHODOLOGY RELATED TO INTEGRATED PRODUCTION SYSTEMS

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INTRODUCTION

If our concern is how to convert some raw material into a particular product, or how to assemble a machine from a set of component parts, a body of technical knowledge exists to enable us to develop ways of performing such operations. If, in addition, we wish to make these operations efficient, techniques exist, and are continually being developed, which enable us to experiment on some form of model of the operations in order to identify 'least cost' ways of operating; where 'least cost' is taken in its general sense of minimum use of resources. Such models are usually based on some form of mathematical representation and the techniques are characterised by guidelines which are precisely defined. If our concern is how to make the above operations effective, as well as efficient, it is necessary to extend the boundary of investigation beyond the physical operations to include the decision-making processes which govern the management of those operations. Once such a step is taken it is no longer clear what the boundary of investigation needs to be. Developing a capability of producing more product, or of assembling more machines quicker and with less use of resources may be seen as improving effectiveness and efficiency from a production point of view, but if production is seen as a service to the company as a whole in achieving its particular set of relationships with its environment, this may not necessarily be the case. Widening the boundary of investigation enables the interactions with other decision-making processes to be explored and a more significant improvement in effectiveness may be achieved by modifying the interactions than by changing the operations themselves.

Widening the boundary of investigation introduces the initial

problem of defining what the boundary should be. It also introduces the equally significant problem associated with the uncertainty of the nature of what is contained within that boundary. Once the investigation extends beyond the physical operations it includes the management processes which interact with the operations and hence includes the multiple perceptions of the managers undertaking those processes. This is what Professor Checkland, in his introductory paper, referred to as the individual Weltanschauungen of the managers themselves.

I have argued so far that, if our concern is for effectiveness as well as efficiency, then it is necessary to extend the boundary of investigation beyond the physical operations to include the associated management processes. In addition, I would argue that the search for effectiveness should be of prime concern, since to be efficient yet ineffective is not very useful. To undertake this search we need some way of describing the area of concern which is rich enough to accommodate the multiple perceptions which exist within, and are an inevitable part of, this widened boundary of investigation. Mathematics does not provide this degree of richness and hence a new modelling language is required. In the opening paper Professor Checkland introduced the notion of a human activity system as an appropriate way of undertaking such a description and here, I am concerned with ways of using this concept as a means of exploring the interactions that exist within an integrated production system. Because of the uncertainty surrounding the nature of such systems I am not concerned with techniques. As already mentioned, techniques are characterised by guidelines which are precisely defined. I am, therefore, concerned with methodology. This needs to be more flexible than technique in terms of its structure and mode of application if it is to be appropriate to the variety that exists in real-world management situations. The application of a methodology may involve the use of techniques, but it is the methodology which determines if a particular technique is appropriate or not. A discussion of methodology related to integrated production systems must however be preceeded by a statement of the area of concern and the nature of the problems characterised by that area to which such methodology could be applied.

AREA OF CONCERN

A concise statement of the area of concern is that it is the control hierarchy that exists in a particular enterprise related to its manufacturing processes. Thus it includes the automatic control systems used to regulate the physical operations together with the higher levels of control associated with these operations. However, there is a crucial distinction between systems containing inert elements (designed physical systems) and systems containing as 'components' autonomous human beings. The major characteristics of human beings in this context is that they are free to attribute

meaning to human activities, to view such activities in a particular way and to act accordingly. The consequence is that the higher levels in the control hierarchy are not simply more complex control systems of the same kind. A management control system (containing people) is fundamentally different from a process control system (containing hardware) in the following ways:

(1) A management control system is highly adaptive, but not necessarily to a consistent and unchanging objective function.

(2) It is capable of self-organisation - hence the controller structure and mode of operation may change temporarily in response to particular disturbances.

(3) Decision-taking responsibility may change as a result of circumstances (for example, it may be determined by who gets what information first and the nature of that information).

(4) The set points to which various levels of management controls are operating may be personal and based upon different views of the desired outcomes.

(5) The response time of any part of the management control system cannot be predetermined. It is a function of many influences.

(6) The elements of a management control system are a set of roles and, although what each role-holder is responsible for can be predetermined, how that responsibility is executed cannot be predetermined. Even though the 'what' remains unchanged, the appropriate 'how' needs to be matched to the situation. In a process controller both the 'what' and the 'how' are predetermined by the design and can only be changed by external intervention.

In summary, a process control system is a designed physical system, and once designed, simply exists. A management control system is a human activity system, and continuously learns and evolves. It can be analysed and 'designed' in terms of sets of on-going activities and the structured way in which those activities are related both to each other and to the enduring purpose of the control system.

Figure 1 illustrates one context in which 'Management Control' needs to be considered. A designed physical system is shown as a process, plus its control system, which converts raw materials into products. The management control system contains this conversion system and operates to achieve the expectations of some business control system, according to its policy but within applied constraints. It needs information about other processes with which it may interact and supplies information about performance back to the business control system so that that system, in turn, can take control action to achieve expectations. Of course, this simple picture represents only one

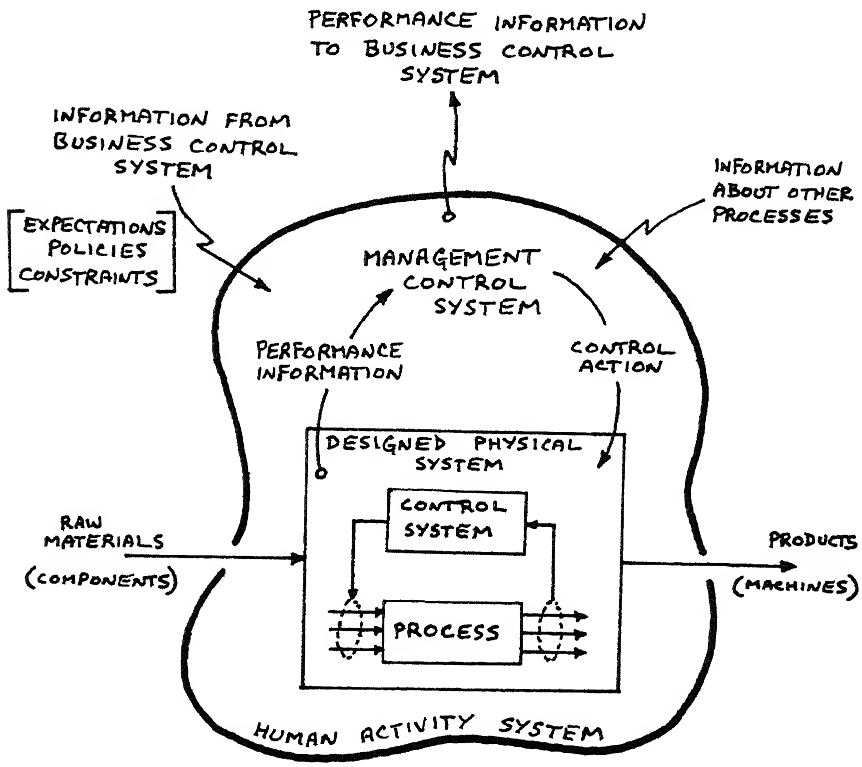


Figure 1: Management Control System

possible view of a management control system; the reader may wish to form an alternative view. This process of selection of a point of view represents an illustration of the special nature of human activity systems. It is unlikely that there would be much disagreement about the definition of the boundary containing the hardware (i.e. the designed physical system) but there may be considerable debate about what constitutes the management control system. Thus a major concern, in analysis of this kind, is to define the boundary of the system under consideration and it is undesirable for this definition to be arbitrary. In a particular analysis, for example, it may be appropriate to include, as part of the management control

system, those activities concerned with maintenance of the production facilities, or those activities concerned with planning (as opposed to scheduling) production. However, if the purpose of the analysis is to improve an existing situation, organisational constraints may be such that these activities have to be taken as 'given' and the boundary of the system defined to exclude them.

An examination of possible systems boundaries can only be undertaken at the same time as an exploration of the possible points of view which could be incorporated and which attach meaning to the system so defined. For example, the management control system could be seen as 'a contribution-maximising system' or 'a flexible-manufacturing-capability maintaining system' or 'a market-satisfying system'. Whatever definition is used (and it is worthwhile exploring the implications of several) it needs to be made explicit as it is against this definition that the systems design, or the improvements recommended, can be logically argued.

Once the system(s) is defined we can identify its contents and questions such as the following need to be answered:

* Within this system boundary, what is the <u>minimum necessary</u> set of activities for the realisation of the <u>particular view</u>?

* What roles are appropriate, in terms of decision-taking responsibility, for what sub-sets of activities?

* What are the relationships between these roles, and hence, what is the structure through which they could operate?

* What measures of performance are appropriate given the particular relationships with activities outside the system boundary (such as the business control system and other management control systems)?

* What information systems are needed to support the activities undertaken and hence what role to role information flows are essential?

This set of questions represents the five broad areas of concern which are relevant to an investigation of the effectiveness of an integrated production (or manufacturing) system. It must be emphasised that the model(s) of the human activity system produced is neither a description of 'what exists' nor some 'ideal'. It is a tool to compare against 'what exists' in order to derive changes

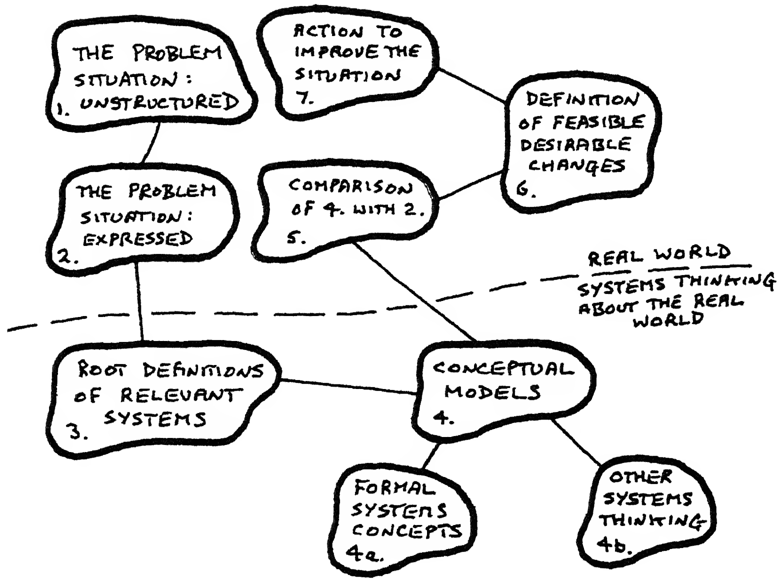


Figure 2: The Checkland Methodology

which, it can be argued, are both desirable and feasible*. The five questions represent the statement of areas of concern for which methodologies have been developed, through our action-research programme at Lancaster, and which will now be presented.

THE CHECKLAND METHODOLOGY

The Checkland methodology (Checkland 1981) was derived experientially and represents the distillation of the learning achieved in a large number of 'action research' projects. It represents the most general methodology applicable to this, and other, areas of concern and is the basis from which other methodologies referred to later have been derived. In essence the methodology can be described as a seven-stage process of analysis which uses the concept of a human activity system as a means of getting from 'finding out' about the situation of concern to 'taking action' to improve the situation. Figure 2 illustrates this process.

* This is why an exploration of several viewpoints can be valuable, since 'what is desirable' is a function of the implicitly held views of the managers in the situation. 'What is feasible' can only be determined from a knowledge of the actual constraints. These may be a function of the particular organisation structure, the social structure, politics or the previous history of development of the enterprise.

The logical sequence illustrated by this figure is a useful way of describing the methodology but it does not necessarily represent the sequence in which it is used. In reality it represents a pattern of activities. An analyst may start with any activity, progress in any direction and use significant iteration at any stage. The dotted line represents the boundary between activity which is in the real world and activity which is related to the use of systems concepts to structure the thinking about the real world. Above the line the language of description will be the everyday language of the particular situation while, below the line, it will be the language in terms of human activity systems concepts.

The first two stages are concerned with finding out about the situation. The first is usually some statement about what makes the situation problematic and some basic facts about it. In relation to our concern here it may be the desire to improve the efficiency of some manufacturing situation. This statement will have been provided by some individual, or group of individuals, in the situation itself. The basic facts presented will be seen to be important (or not important) to the analyst according to some Weltanschauungen (Ws). Part of the finding-out stage will be to identify what these Ws might be and to raise questions about what other Ws might also be relevant. This stage is particularly difficult in practice and the analyst must be careful that he does not impose his own W on the situation. It is attempting to be neutral that is difficult and to avoid tailoring the subsequent analysis to fit readily derived 'solutions' from the initial 'finding out'.

At some point the analyst will decide that he has a rich enough picture of the situation to name some human activity systems that he believes will be relevant to the analysis. This step is a matter of judgement and the analyst has to live with the uncertainty that what he has chosen may turn out not to be relevant. This does not matter since the learning achieved in reaching that decision will enable him to make a more relevant choice. These human activity systems are defined by constructing root definitions which specify what the system is and conceptual models are then produced (in terms of minimum, necessary activities) which specify what the system must do in order to be the system so defined. The analyst is not attempting to define a system that ought to exist because, as argued earlier, 'what ought to exist' will be seen differently by the different managers involved. Producing several root definitions and models will help to avoid any hoped-for utopian analysis. The analyst is seeking root definitions of systems that are relevant, where this means relevant to producing insight.

Since these conceptual models are not descriptions of what exists validation of them, (in the sense that a simulation model of a production process can be validated), is only possible by ensuring

that they represent well structured models. Help in achieving this can be derived by comparing them against the model of any human activity system (formal systems concepts of stage 4a) and by making use of any other systems thinking (stage 4b). For example, I have found the concept of an adaptive control system from control engineering to be particularly helpful.

Once these models have been developed, the analyst can use them to compare against what he has found out about the situation in order to identify changes that can be argued to be desirable, on the basis of the analysis and the evidence collected from the situation, and feasible, given the particular culture, history and politics of the situation.

It is at the stage of comparison that the analyst will learn whether or not the choices were indeed relevant. It is this learning that may be the source of iteration referred to earlier. In essence the whole methodology represents an explicit, structured learning process which is completed by deriving the necessary action to improve the situation based upon the changes identified that meet the two criteria stated.

This methodology is particularly relevant to the question concerning what to take to be the boundary of investigation and the nature of what is then contained within that boundary. To illustrate this feature of the methodology I will refer to an actual project which was undertaken for a particular works within a chemical company. The statement of the problem situation was that the works had grown over a number of years and the senior management were concerned that a number of procedures were being operated for historical reasons and may no longer have relevance, and that some procedures should be developed which were more appropriate to their current needs. In other words, they were concerned about the effective use of their resources, in particular their manpower resources. Following a series of interviews with the senior managers, I selected three root definitions of systems that I believed were relevant in that they took boundaries that were close to the organisational boundary of the works, (so that changes identified would be within the decision-taking authority of the senior management), but which also recognised the interactions between this works and others at different geographical locations and with the company itself. In order to maintain confidentiality we can take the company to be the Cookwell Chemical Co. with the particular works situated at Kirkby. The three root definitions chosen were:

R.D.1

A Cookwell Chemical Co. owned system which responds to the company for the effective manufacture of a broad range of chemicals and which seeks to be a major supplier to both the Company and the

market within the constraints applied by the Company and the Kirkby environment and at a performance acceptable to the Company.

This definition takes the view that the system is reactive to company demands but, since it seeks to be a major supplier, it implies competition with the other works within the company.

R.D.2

A Cookwell Chemical Co. owned system which seeks to survive and establish its security by maximising its contribution to the ongoing profitability of the company whilst having due regard to the interests of employees, shareholders and the general public.

This definition was extracted from the published objectives of the works and takes the view that maximising contribution will ensure survival and security. It says nothing about manufacturing chemicals, but as it was produced by the senior management of a chemical company, I included a set of related activities within the model that were not strictly justifiable from the root definition.

R.D.3

A Cookwell Chemical Co. owned system which seeks to fulfil its agreed role within the company by maintaining a viable manufacturing site, capable of meeting the continuing needs on the company by being highly professional and competitive in relation to its own areas of business whilst maintaining a responsible attitude towards statutory and environmental constraints.

This definition takes the view that it wishes collaboration (not competition) with the other works within the company, since it is seeking to fulfil an agreed role, but it also wishes to be competitive within the general area of its business.

The models derived from these three root definitions are illustrated, respectively, by figures 3, 4 and 5.

Each model represents the set of minimum, necessary activities that are logically defensible from the root definition and the arrows represent logical dependencies. Even though the models are at a very broad resolution level, they provided a useful basis for the first comparison stage.

In this particular project the senior management were familiar with the systems language (due to a number of seminars held within the works) hence the first comparisons consisted of a debate about the desirability and feasibility of the activities within the three models. It is more usual, however, to derive a set of questions based on the activities and to carry out the comparison in the language of the situation. As a result of this debate a further model

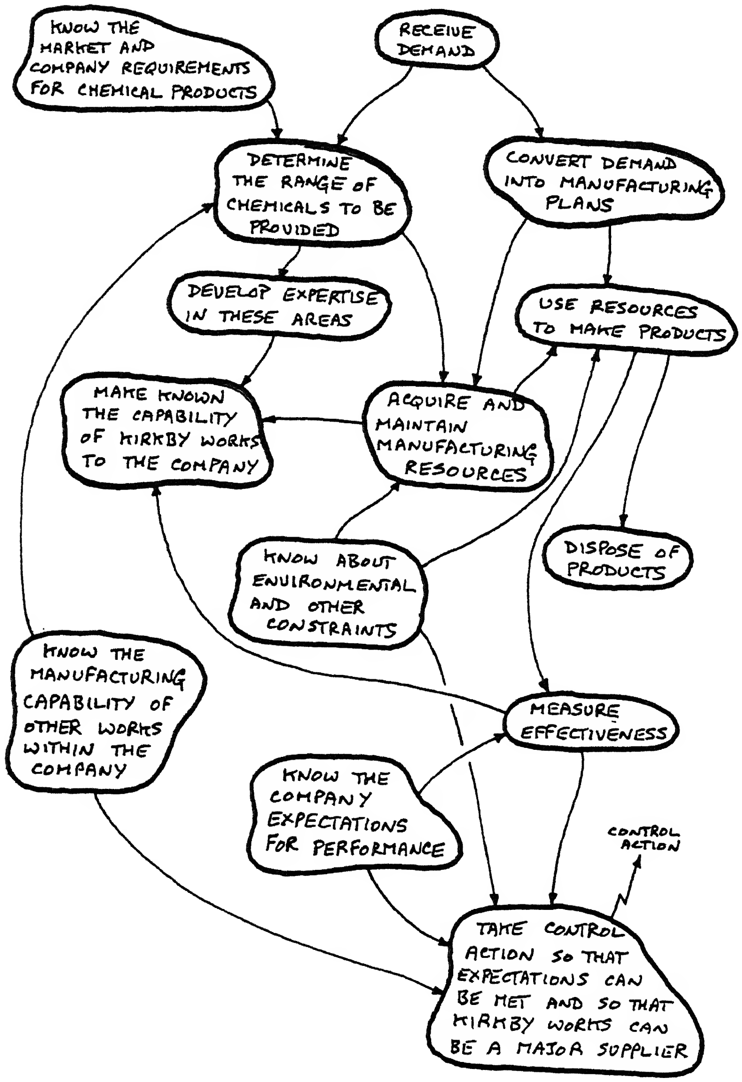


Figure 3: Model of R.D.1

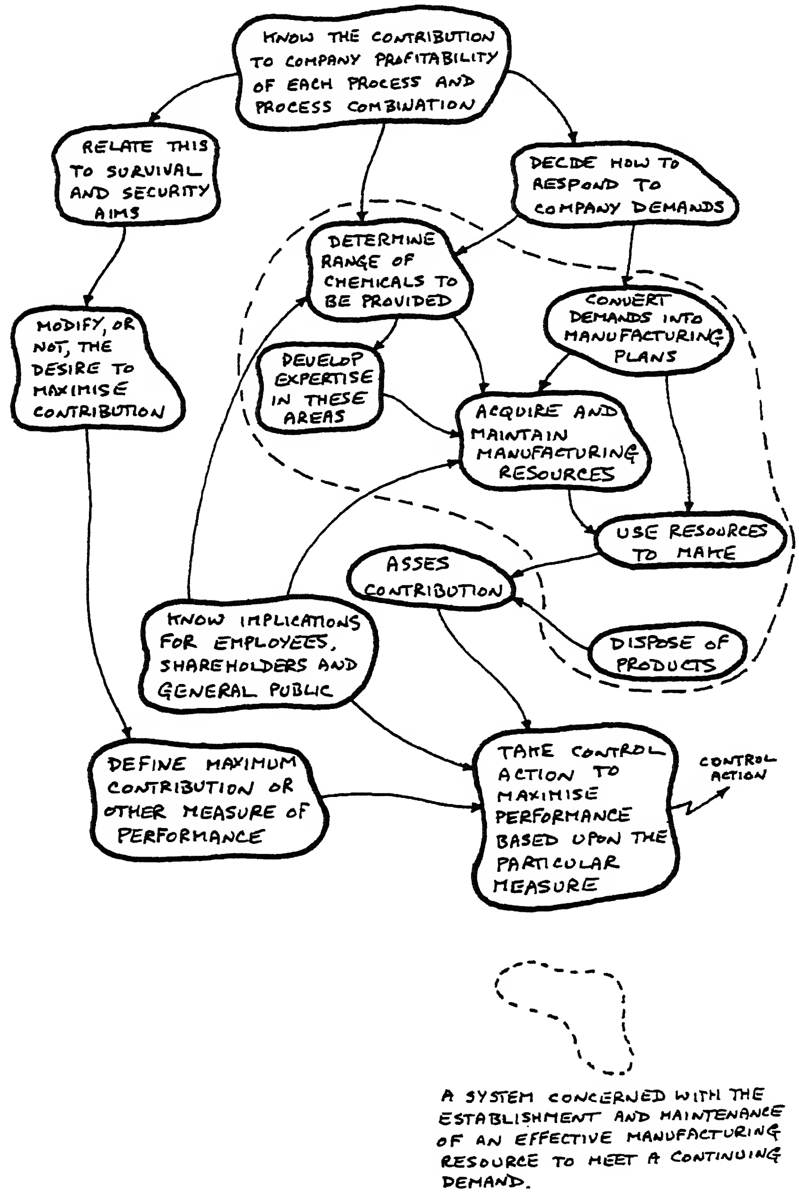


Figure 4: Model of R.D.2

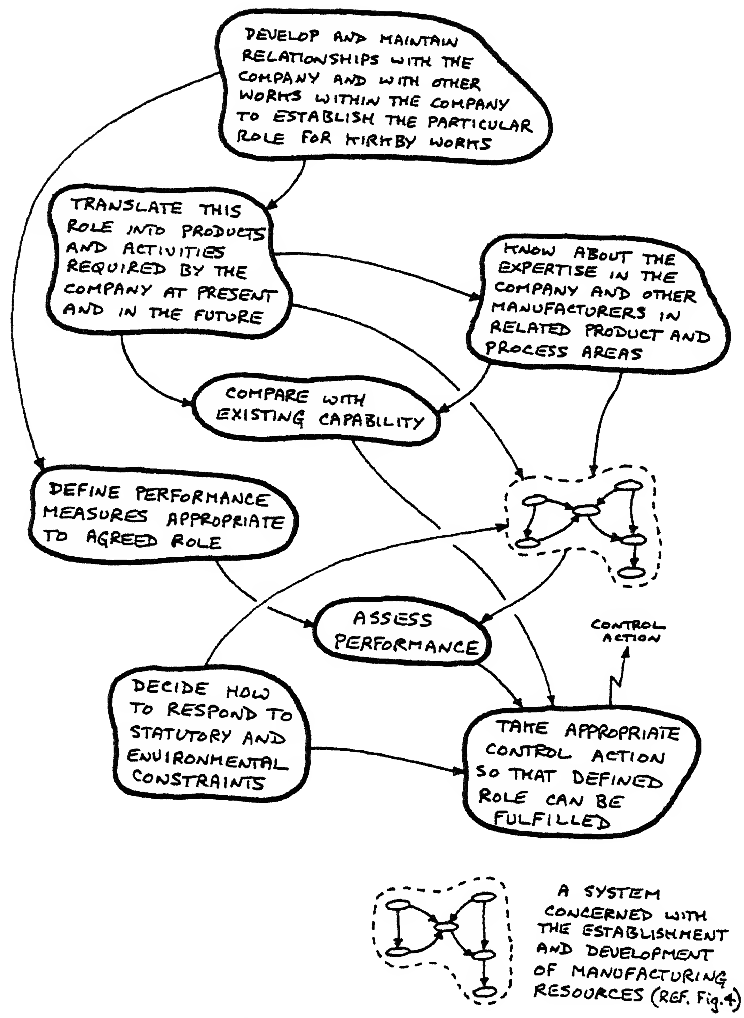


Figure 5: Model of R.D.3

was derived, which was oriented towards the model from root definition 3, and this was developed through a hierarchical expansion (by taking each activity to be a system and developing a R.D. and model) to a level of resolution of around 80 activities. It was this model that was then used to identify procedural and organisational changes through a more detailed comparison.

The three root definitions were all legitimate, in terms of the views expressed by the managers during the initial interviews and, whereas a debate about the root definitions would not have been useful, the discussion structured around the minimum, necessary activities proved to be highly enlightening. For example, the set of objectives, which lead to R.D.2, had been previously agreed by the senior managers, yet a number of activities were also agreed to be infeasible, thus rendering the objective infeasible. Following this kind of exploration the analyst has available both a definition of the boundary of investigation (the root definition) and a description of the nature of the activities contained within that boundary (the conceptual model).

ISSUE BASED AND PRIMARY TASK ANALYSIS

Before discussing further developments of the Checkland methodology to aid analysis related to the remaining areas of concern identified earlier, I would like to return to the stage in that methodology where a selection is being made of relevant systems. Although the choice is entirely up to the analyst, given the particular situation of interest, it is possible to provide some help in that choice by considering a distinction between two types of analysis. In practice this is not a clear distinction, but it is helpful to consider if the nature of the concerns being expressed tend to suggest one kind of analysis or the other. These are termed ISSUE BASED or PRIMARY TASK analyses. (Checkland and Wilson, 1980).

In the project just described, for the Cookwell Chemical Co., an issue-based analysis was being undertaken; the issue being the nature of the role for Kirkby works. In any study, where it is felt to be of value to explore the implications of a number of different Ws and/ or a number of different transformation processes, an issue-based analysis is almost certainly the one to be pursued.

There are instances, however, particularly in relation to problems concerning the re-structuring of organisations, or to information systems analysis, where it is of value to consider a primary task choice of root definitions. Essentially one is choosing to model a version of the situation which, it can be argued, is close to agreed perceptions of reality. Thus if an organisation is concerned with manufacturing cars, one can actually observe that components enter the company and cars emerge. Hence it may ge argued that a certain set of activities must exist (irrespective of how they are done) in

order that the transformation can take place. Thus, when carrying out a primary task analysis, the root definition chosen will lead to the model of a notional system which can be related very directly either to an organisation as a whole or to a well-established task carried out by a section, department or division of the total organisation. In such studies a chosen relevant system is likely to be one which expresses the public or 'official' explicit task which is embodied in the organisation or section or department. Such a choice takes as given that a certain explicit task is to be performed by or within an organisation (without taking as given existing organisational boundaries) and then requires an RD and systems model which expresses this 'primary task'. In many studies located in manufacturing industry, for example, a chosen relevant system has been one which transforms raw materials into saleable products. And in a recent major project a primary task RD described a notional system to carry out the task assigned to the engineering division of an international airline, namely to carry out planned maintenance on a fleet of aircraft effectively and efficiently under various constraints. It would be hard to argue that within an airline there might not be a manifestation of such a system, hence this is a good example of an RD of a relevant system of the 'primary task' type. It expresses a primary task which must be manifest if the real-world organisation is to be capable of fulfilling its public function.

Although the distinction between primary task and issue-based analysis is one that it is useful to consider at the root definition selection stage, a primary task analysis will, almost certainly, need to be preceeded by an issue-based analysis. 'What to take to be a primary task description' is itself an issue which must be explored. In the project referred to earlier, the issue-based analysis was the initial stage in the derivation of a primary task description relevant to the Kirkby works.

A METHODOLOGY FOR RE-ORGANISATION

The Checkland methodology, used to identify a primary task description of the organisation (or part of the organisation) under review, is applicable to the first of the five questions identified in the section 'Area of Concern'. The remaining questions can be addressed through the application of two further methodologies; one related to information systems analysis and one related to re-organisation. Since the latter forms part of the former, the methodology related to re-organisation will be described first.

During the construction of a primary task model relevant to an organisation several levels of resolution will have been developed. Since the activities at any one level are seen as the set belonging to a system at the previous level, it follows from the definition of a system boundary, that there is a decision taking role already

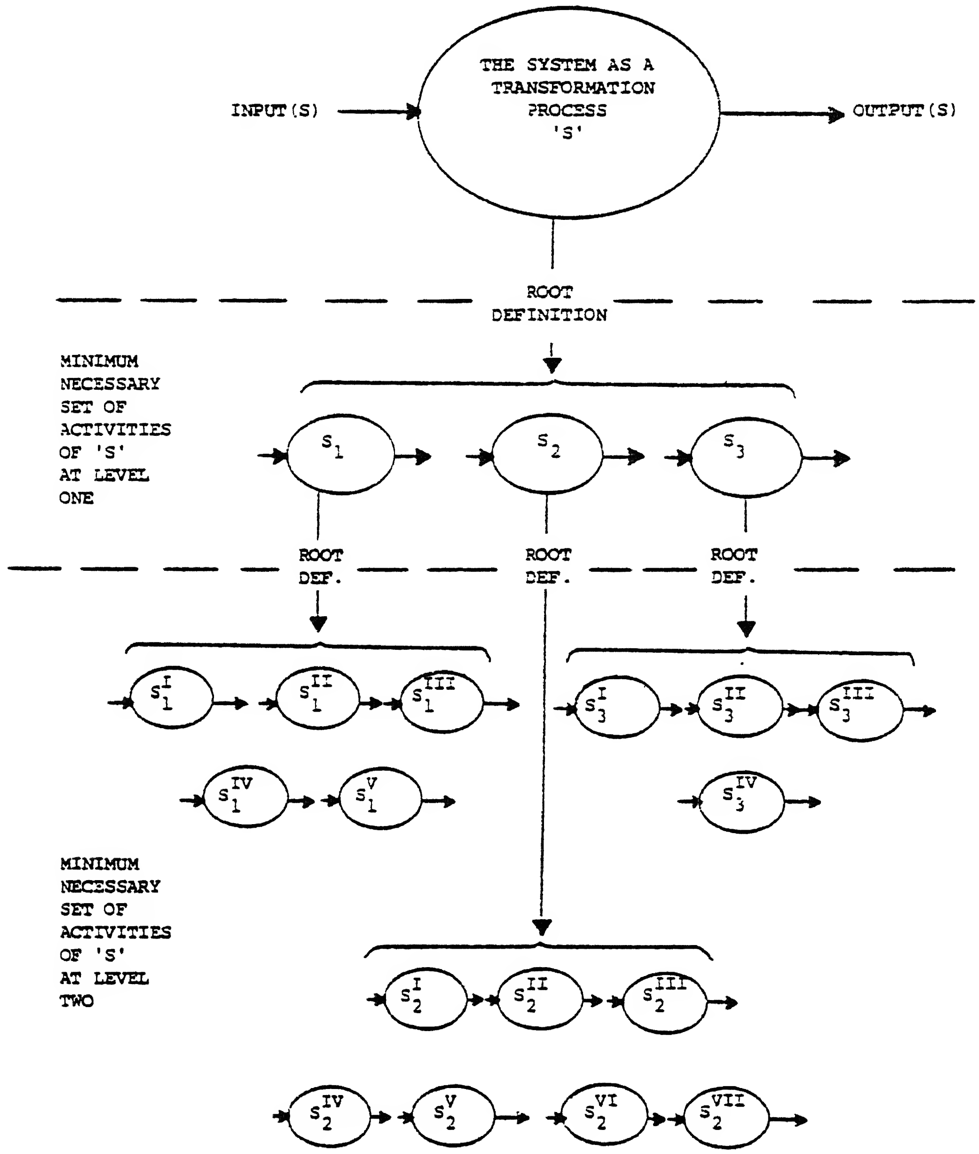


Figure 6: Model Development

established. Hence, referring to Figure 6, it is implied that the authority of the decision-taker in system 'S' extends over activities S1, S2 and S3. Similarly the area of authority of the decision-taker in system S1 extends over activities $S_1{}^{I}$ to $S_1{}^{V}$ and so on. Thus, in a design mode, the decision-taking roles could be defined on the basis of the systems hierarchy. Role definition then becomes dependent upon the way in which the model is expanded.

In the analysis of an existing situation the decision-taking roles established by the model (Map 1) are used for comparison against the actual areas of decision-taking responsibility within the organisation (Map 2).

The comparison of the two maps is used to initiate debate about the appropriateness of any current responsibilities which are different from those derived from the systems model. The result of this debate is either to change the responsibility within the organisation or to modify the systems model. Thus at any resolution level convergence is obtained between the systems boundary and the organisational boundary prior to development of the model at the next resolution level.

The particular project within which this mapping technique was developed (Wilson 1979) was again at the scale of 'a works' within a division. This was a manufacturing company in the communications business and the concern was 'how to develop a rationale for re-organisation in the face of a changing market'. An activity model was built, based upon the expansion of the following major sub-systems within the total organisation:

A 'develop products' sub-system
A 'develop markets' sub-system
A 'make products' sub-system
A 'customer contact' sub-system
A 'control' sub-system

The titles of the sub-systems were chosen to be unrecognisable as organisational groups within the existing situation in order that a clear distinction could be maintained between a sub-system (and the activity groups derived from it) and the departmental groupings that happened to exist in the company at that time.

This activity model (at the level or expansion of the above sub-systems) was drawn on a large base chart. Figure 7(a) is a representation of this model in terms of notional activities. The actual model contained about eighty activities, and it is impractical to try to represent it here. Figure 8 indicates the kind (and level) of activities included within the 'make products' sub-system.

Using a transparent overlay, boundaries appropriate to the original sub-systems were drawn, using a different colour for each sub-system. This process is illustrated in Figure 7(b).

What is now available is a definition of decision-taking responsibility for groups of activities based upon the conceptual model. The next stage is to remove overlay I and replace it by a second transparent overlay. For each of the activities on the base chart the question is asked: "Who in the present situation has the

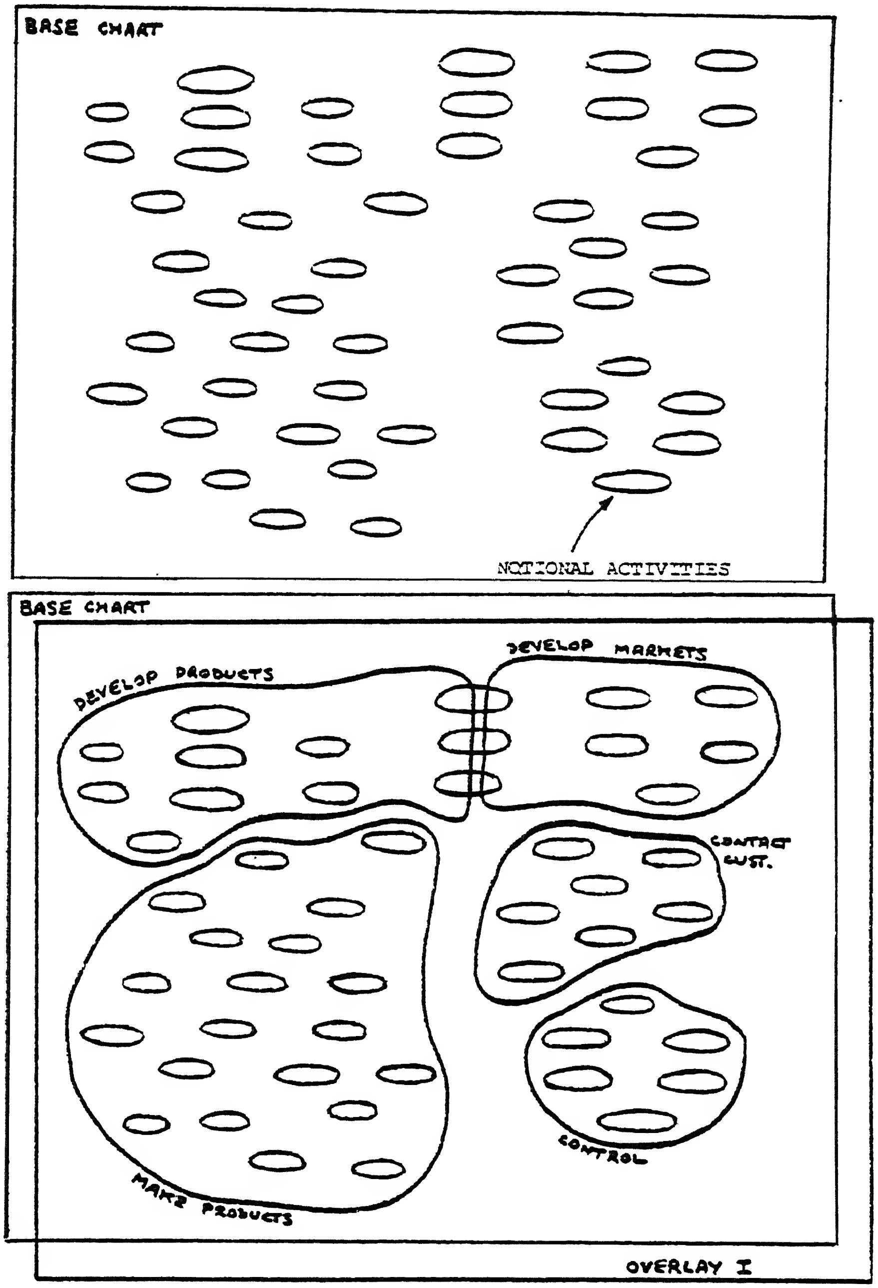


Figure 7(a): Base chart showing assembly of second level activities.
7(b): Base chart with overlay I showing allocation of activities to sub-systems.

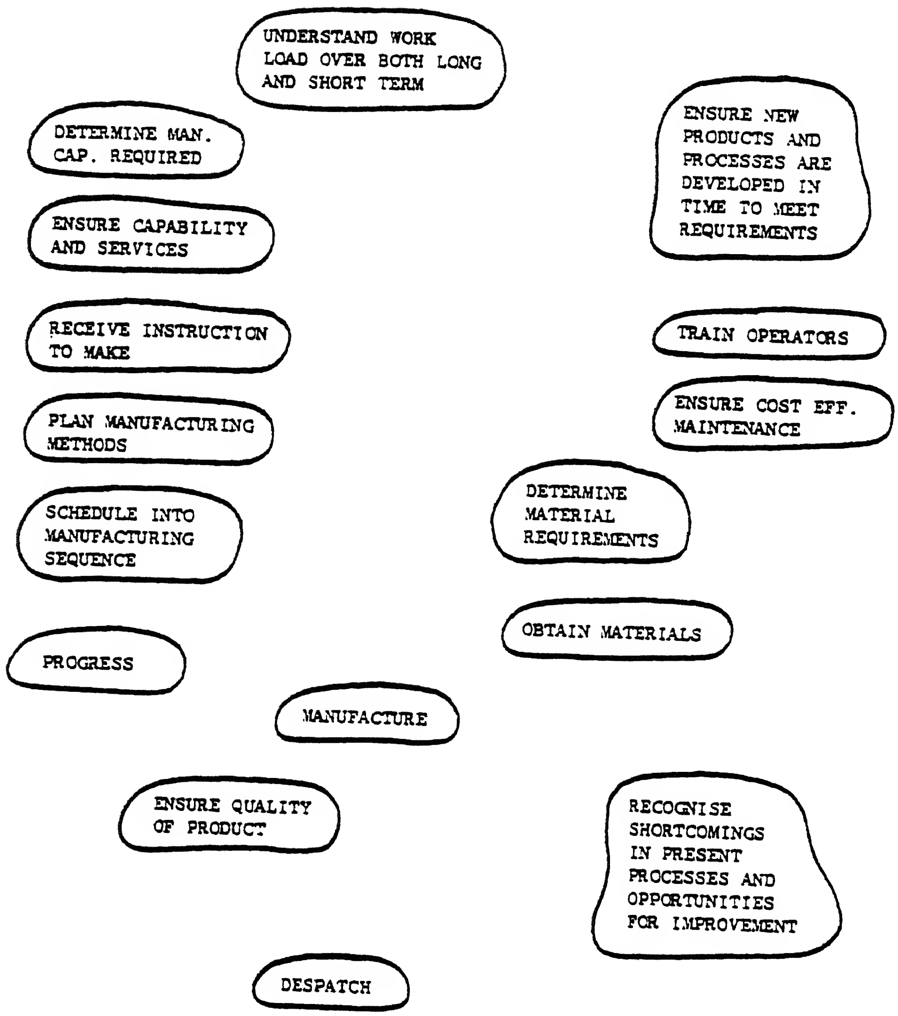


Figure 8: 'Make' System: Second Level Activities Excluding Interactions Between Activities

decision-taking authority for this activity?" The second overlay is then annotated with an appropriate departmental identification. The classification used in this example together with the related sub-system was as follows:

- T - Technical Development Department (approximating 'develop products')
- M - Manufacturing Department (approximating 'make products')
- E - Production Engineering Department (no equivalent sub-system)
- CC - Sales Department (approximating 'customer contact')
- C - Senior Management Group (approximating 'control')

Once this annotation has been completed, the first overlay is replaced and the differences between the conceptual and the actual allocation of responsibilities becomes apparent, illustrated by Figure 9(a). The basic premise, in the systems allocation, is that there should be a single decision-taking authority for the activities contained within the system boundary. Where this is not the case, these activities are designated 'island activities'.

The identification of the island activities directs the debate to possible anomalies in the organisation structure and at this stage decisions need to be made either to change the responsibilities or to move those activities to the sub-systems relevant to their allocated responsibilities. In some cases current responsibilities could not be identified (particularly in relation to some of the marketing-type activities; this was a reflection of the changing market situation) and in other cases the boundaries were seen to cross activities. This meant that, in this latter case, the activities had to be expanded to allocate them to one sub-system or the other. Figure 10 gives, as an example, a set of island activities within the 'make products' sub-system.

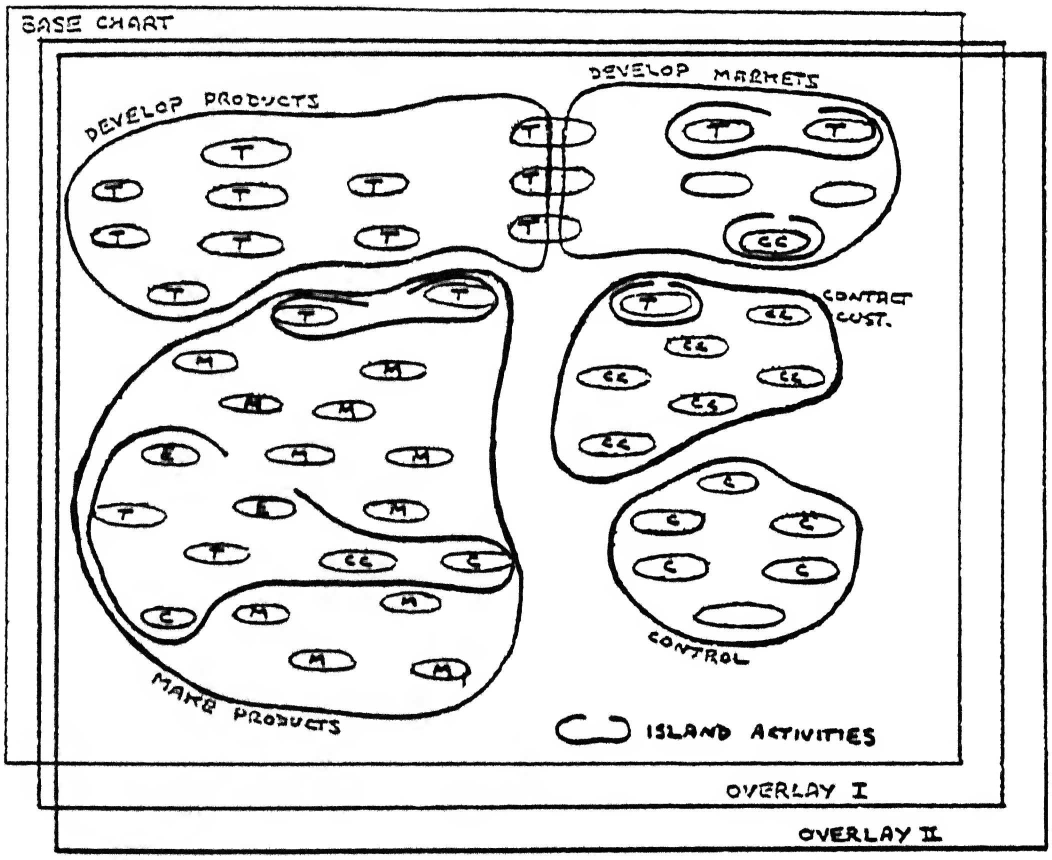


Figure 9(a): Base Chart with Overlays I and II Showing Identification of Island Activities

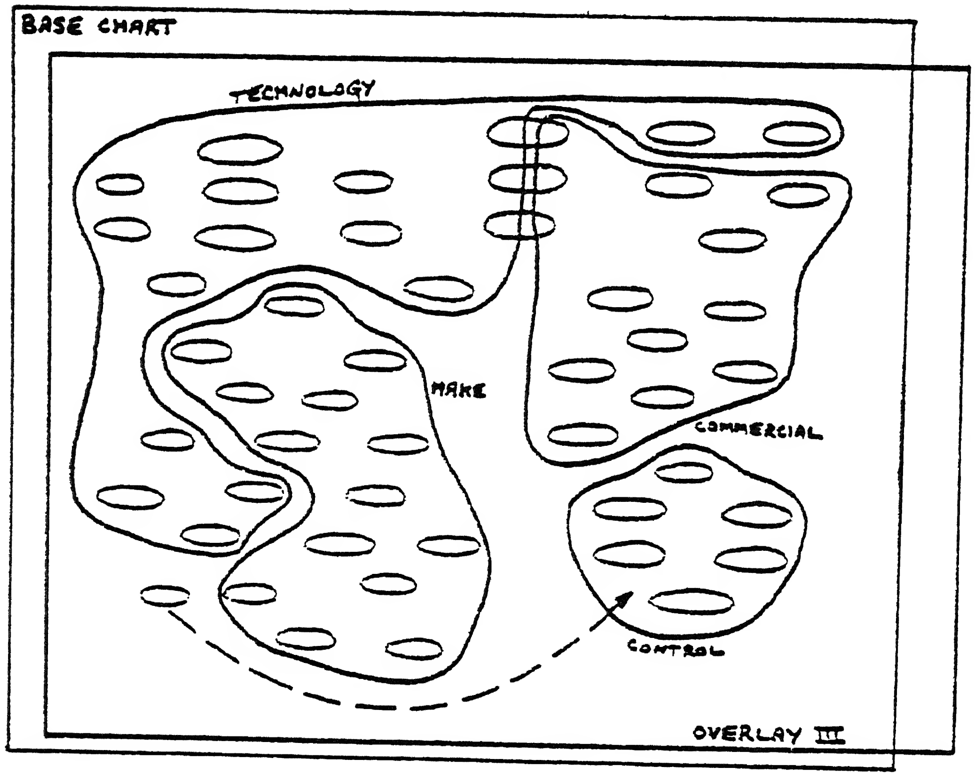


Figure 9(b): Base Chart Showing Assembly of Second Level Activities and Their Allocation to the Modified Sub-System

These activities relate to the large 'island' illustrated in Figure 9(a) where the 'make products' sub-system contains several activities which are the actual responsibility of Technical Development, Production Engineering, Sales and Senior Management. The solution adopted to this problem of diverse responsibilities was that shown in Figure 10, where some of the activities have been moved to the Technical Development sub-system. The major decision activity on capital expenditure is retained within Divisional control (Senior Management) and the responsibility for the remainder lies firmly within the 'make product' sub-system.

The need for a separate Production Engineering responsibility disappeared and this reallocation of responsibilities as indicated in Figure 10 was accepted as reasonable in this particular situation. The decisions concerning island activity responsibilities were made by senior line managers concerned. Thus what emerged from the analysis was an organisation structure that they had developed (and hence felt they owned) rather than one imposed either from outside or from above.

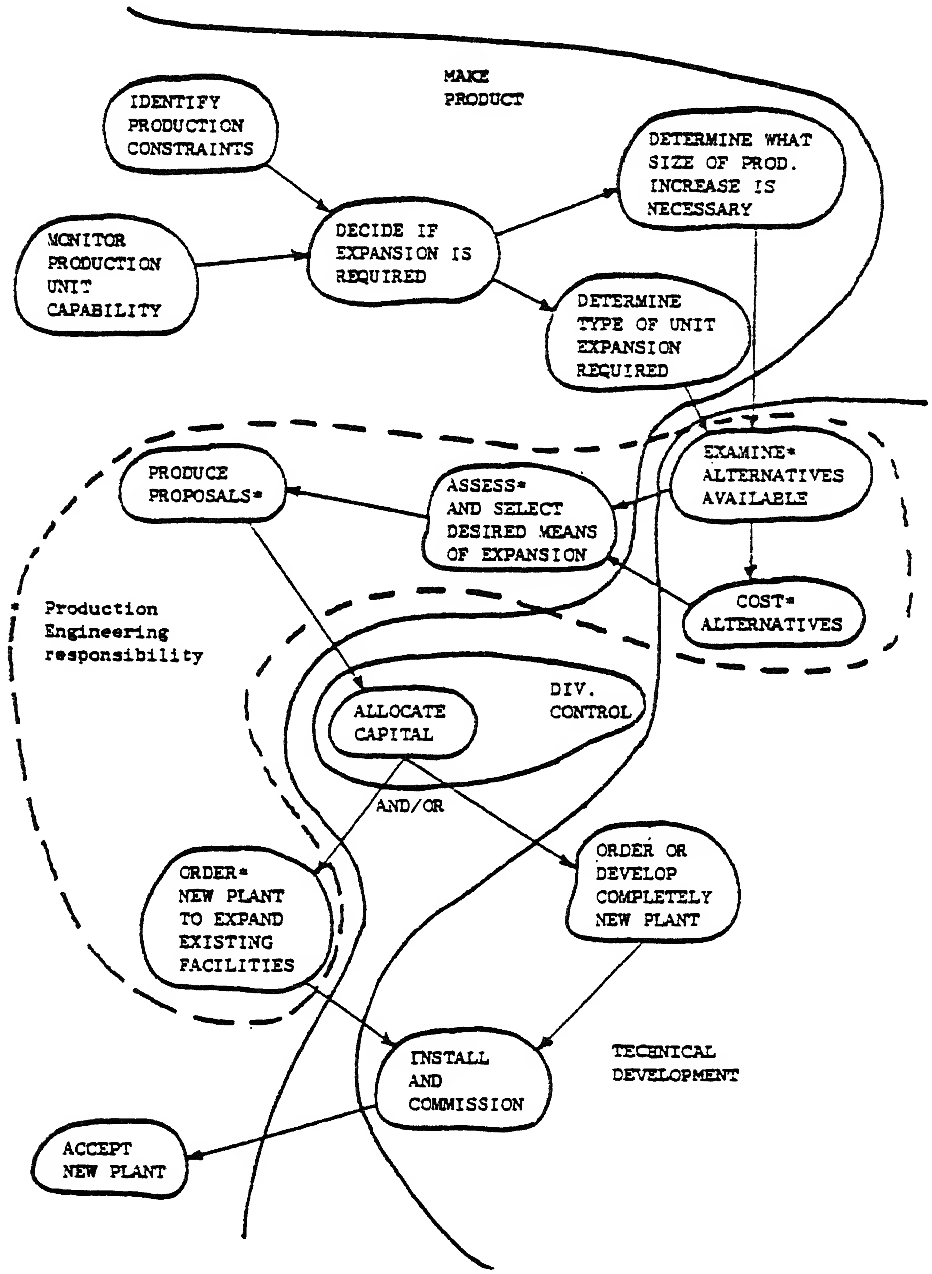


Figure 10: Island Activities Within 'Make Product' Sub-System

In the actual project there were many such islands and a considerable amount of time was devoted to examining the alternatives available. There was no right answer and the solution in each case represented a compromise, but nevertheless, a compromise that the senior line managers believed to be the best and which represented a situation they felt confident to manage.

Once the 'island' questions had been resolved a set of sub-system boundaries existed which were consistent with acceptable organisational boundaries, within which there was no duality of responsibility. In carrying out this procedure the root definition of each of the sub-systems will have been changed by the addition or subtraction of activities and it was, therefore, necessary to redefine them and to ensure that they still represented a self-consistent set.

On completion of this stage of the analysis the sub-system boundaries are redrawn and overlayed on the base chart as in Figure 9(b). The names of the sub-systems have been changed to indicate that their root definitions have been modified by the reallocation of activities.

These sub-systems now represent new organisation units, and the analysis proceeds by taking each sub-system, treating it as 'the system' and repeating the analysis at the next level of detail. For example, the 'make' sub-system was seen to consist of four major activities:

Acquire raw materials
Plan production
Produce
Ensure service utilities are available

In the particular project described, five such base charts were constructed, one for each new sub-system (or, as it now was, new department) and the mapping process continued. The managers involved at all stages in the decisions concerning island activities were those at appropriate levels in the organisation. The analysis was carried out from general manager level to foreman level; and since it involved the people concerned it became also the process of implementation.

This particular experience indicated the practicability of using systems models and the overlay technique to define roles in an existing organisation.

INFORMATION SYSTEMS METHODOLOGY

The identification of the boundary of investigation related to an improvement in production or manufacturing effectiveness can be undertaken using the Checkland methodology and the use of a primary

task description can lead to the definition of the set of activities (primary task model) contained within the appropriate boundary. The methodology for re-organisation can then be used as a means of exploring the appropriateness, or otherwise, of existing decision-taking roles on the basis on a comparison with defined groupings of activities from an expanded version of this primary task model.

The remaining questions, concerned with Information provision, both as support to these activities and for the control of these activities (based upon derived measures of performance), can be addressed by making use of an information systems methodology (Wilson 1980, 1982). This methodology is concerned with what is known as the 'front end' stage of analysis. The purpose of this analysis phase is to answer the question: "Who in terms of role needs what information for what purpose?" It is not, at this stage, concerned with how that information might be provided. The design phase decides whether the information is processed by computer or by manual methods, the source of the data, and such things as whether that data is contained within a central or distributed data base.

The approach described here makes the assumption that it is sensible to derive the information needs on the basis of a model of the particular organisation which is independent of the organisation structure and then, and only then, to relate the information flows to the existing set of management roles. In broad terms, this approach consists of the following stages:

(1) Develop an activity description of the organisation (or part of the organisation) under review (i.e. a 'primary task' model). Dependent on the scale of the study, it may be necessary to derive a number of activity models at several levels of resolution in order to fully describe the information needs.

(2) Derive the categories of information required to support the activities in the models and the particular activities from which this information can be obtained.

(3) For a particular organisation structure, define management roles in terms of the activities for which each existing role-holder has decision-taking responsibility. (If the organisation structure is not a constraint, the approach described earlier can be used to explore alternative role definitions.)

(4) Use these role definitions to convert the 'activity to activity' information flows in (2) above into 'Role to Role' information flows, i.e. define the particular information needs of a manager based upon this analysis of the activities for which he is responsible.

These information requirements define the information (processed data) which the data processing network needs to provide. Since these requirements are based upon a set of minimum, necessary activities, they represent the crucial information needs which should be provided by formal data processing methods. Other non-crucial information (to support the social needs, for example) can remain unaffected by this analysis. Stage 2 above requires the use of some method to assemble the conceptual information flows and to relate these to what is already provided in the existing situation. During a recent project, a device known as a 'Maltese Cross' was developed for this purpose and, since this is now an integral part of the methodology, its structure and assembly will now be described.

THE MALTESE CROSS

In essence, the maltese cross is a four-part matrix. The upper half contains the activities taken from the activity model (derived in Stage 1 of the approach described in the previous section), together with an indication of the activity-to-activity information flows (Stage 2). The lower half contains a statement of the existing information processing procedures (I.P.P.s).

Figure 11 illustrates the structure of the maltese cross. The north axis is a listing of the set of activities making up the 'primary

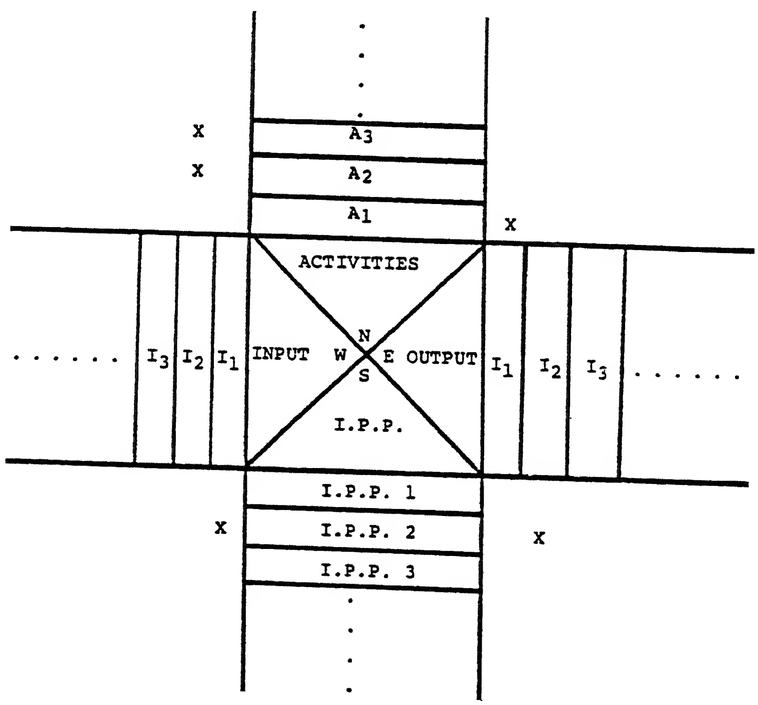


Figure 11: Structure of a Maltese Cross

task' system relevant to the particular area or organisation under review. The east and west axes are identical and contain the information categories deemed essential for the support of the activities at this level of resolution. The east axis (representing inputs) is the mirror image of the west axis (representing outputs). The south axis is a listing of the Information Processing Procedures (A.D.P. and manual) and represents the existing state of the information processing network prior to the review. If the purpose of the review is to examine the potential for computer-based processing of an existing manual network, the lower half of the maltese cross will represent the complete manual systems, illustrating their scope and interactions. If the situation is entirely 'green field', the lower half will be blank.

Referring to Figure 11, the x in the SW matrix indicates that data belonging to information category I1 is used by I.P.P.2 to produce a processed output in the information category I2, (SE matrix). The NW matrix shows that this information category I2 is required as input to both activities A2 and A3. The x in the NE matrix shows that the information category I1 is produced by undertaking activity A1, and hence this activity (or the manager responsible for activity A1) has the capability of updating the category and thus providing timely data as input to I.P.P.2. The significance of the two x's in the NW matrix is that since they show that I2 is an essential input to both A2 and A3, the managers responsible for those activities must have access to this particular output of I.P.P.2. In practice this may not be the case, particularly if the development of I.P.P.2 had been initiated by only one of them. If the same manager is responsible for both A2 and A3, this is not likely to be a problem.

The maltese cross is completed by filling in all the x's in the NW and NE matrices to give a complete picture of the activities and the activity to activity information flows deemed relevant to the area of concern in Stage 2 of this process. In the SW and SE matrices a picture is obtained of all the I.P.P.s used to process information and the information processed. Relating the bottom half of the maltese cross to the top half will enable a set of questions to be asked of the whole information processing network directed by the existence of a potential lack of coherence indicated by a number of x's in the same columns of the SE matrix. Such questions are:

* Does the existence of more than one I.P.P. providing an information input to an activity indicate a duplication of data processing?

* Could more efficient processing be obtained by utilising data already processed by one of these I.P.P.s rather than by processing raw data?

* Do the existing I.P.P.s and their outputs fulfil the total information needs of each activity?

* Are the respective formats of the outputs of the I.P.P.s supporting the same activity, consistent and is this format the most useful for the purpose of that activity?

* Is the data provided by the I.P.P. required as a support to activities other than those for which it is to be, or was designed?

These questions can, of course, be asked of an existing information processing network or asked when it is proposed to develop a new I.P.P. for introduction into the network. The maltese cross does not provide the answers but it directs the questions to the relevant areas.

AN APPLICATION

To return to the methodology and to illustrate its use I will refer to a recent project undertaken in Mexico and make use of part of the analysis that was done. The company was called Ponderosa Industrias SA (P.I.S.A.) and was concerned with the manufacture of wood products, chemicals, paper and with the cultivation of pine forests as the source of raw material. A number of companies made up P.I.S.A. and this in turn was part of a larger group of companies called the Chihuahua Group. This included non-industrial concerns such as banking and insurance. The project was centred on P.I.S.A. and was concerned with the provision of information for the control of operations together with the supply of that information that was required for performance reporting to the larger group.

The first stage in the analysis was to develop a primary task model relevant to P.I.S.A. and to do this the following root definition was derived:

A Chihuahua Group owned system for the conversion of a partially managed natural resource into defined end products and intermediates, for continued profitable sale, with a performance which meets the expectations of the owner but within Group, community and Government applied constraints.

Most of this definition is probably understandable with the exception of 'partially managed'. This term was included because the short-term management of a forest was the responsibility of a

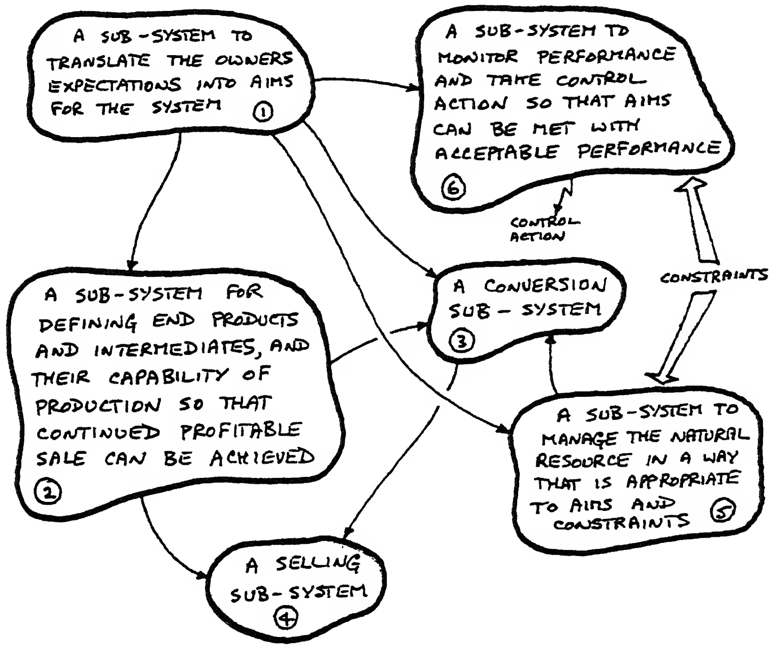


Figure 12: First Level Model

local woodsman, who was not an employee of P.I.S.A., whereas the longer-term development of the forest, the provision and maintenance of machinery and roads was the responsibility of the forest group within P.I.S.A. The model resulting from this definition at the first level of resolution was in terms of a set of sub-systems and is illustrated by Figure 12.

A root definition for each of these sub-systems was derived and the model expanded to a level containing around fifty activities. Further selected expansion was necessary to be able to usefully derive support information but as an illustration of the process let us consider only the activity 'obtain raw materials' which appeared from the expansion of sub-system 3. The root definition taken for this system was:

A P.I.S.A. owned system to obtain and make available that material required by the conversion system so that production requirements can be met within inventory and other company applied constraints.

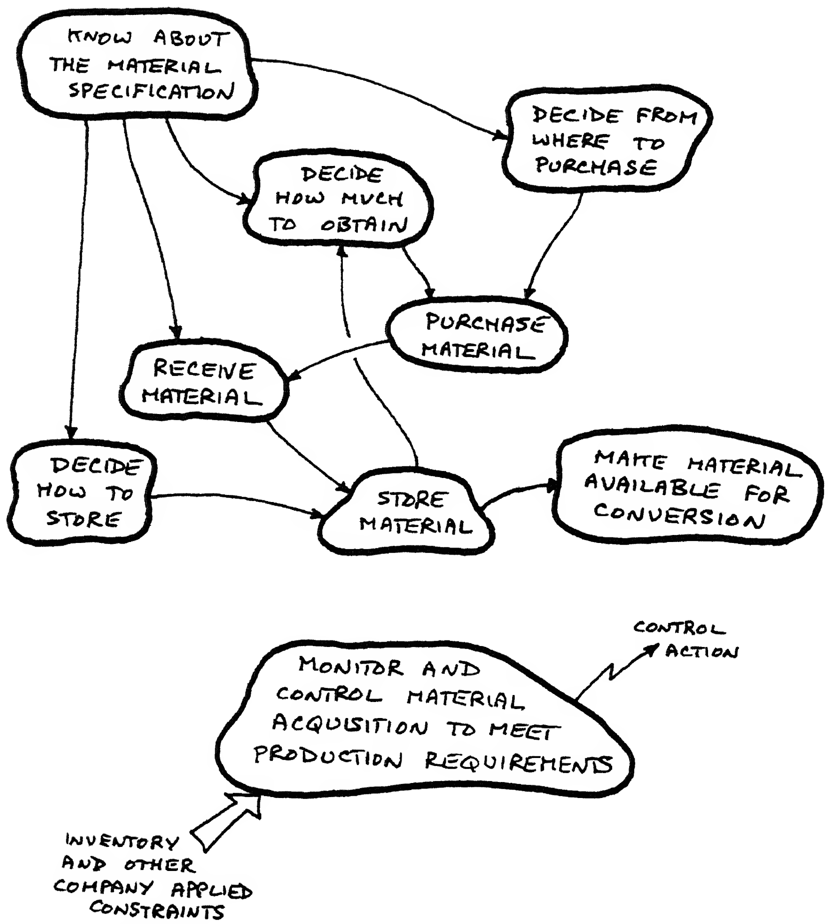


Figure 13: 'Obtain Raw Materials' System

The resultant model is given in Figure 13. For each activity within this model, (with the exception of the activity 'know about material specification'), the input information categories were derived followed by the identification of those activities that generated these information categories as output.

An activity of the form 'know about ......' is itself an information generating activity and its input and output are identical. In this case the information category is 'material specification' and it appears as input to the other relevant activities. A 'know about' type of activity merely indicates that the actual source of the information is external to the system being considered.

Control information (i.e. that to be monitored) was derived from measures of performance that were determined for each activity.

The results of this stage in the analysis are contained in the table 1. It is at this stage also that the information categories themselves are defined. This is done through the derivation of a data model for each category. Two examples are given below for the information categories, 'supplier data' and 'demand'.

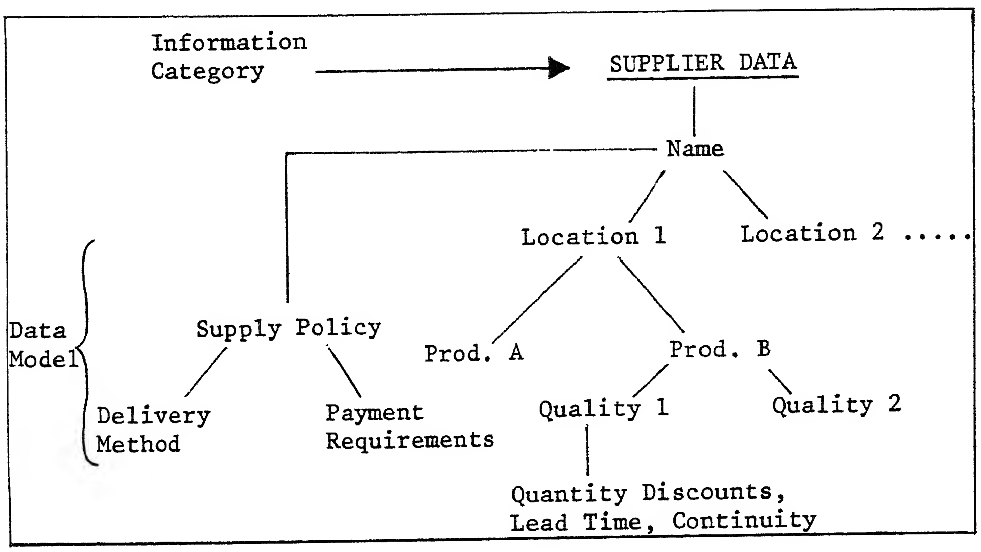
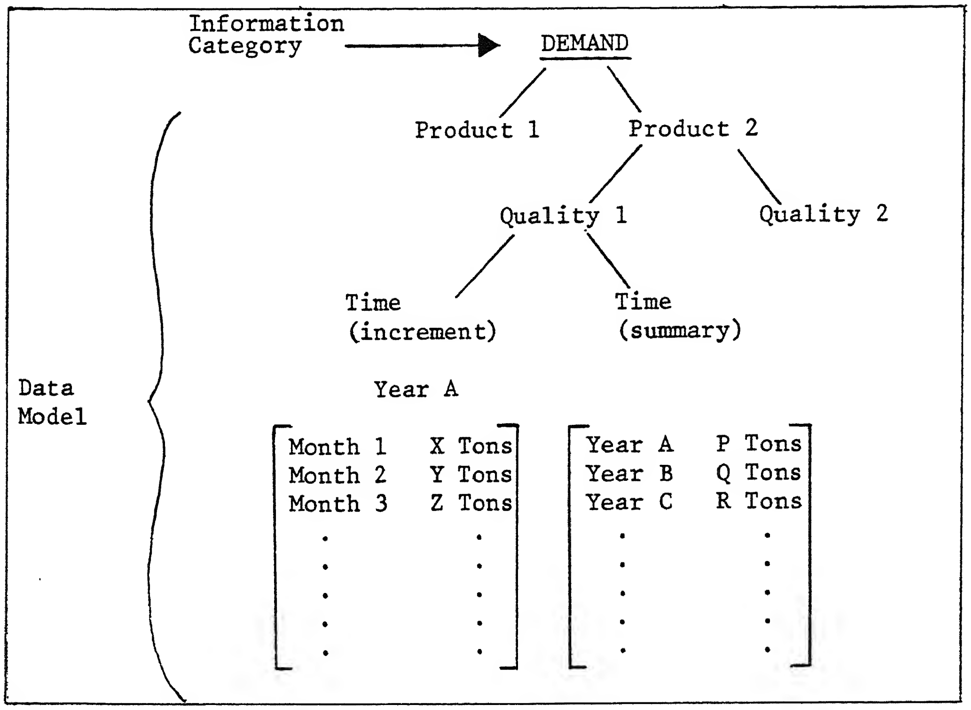


Table 1: Information Categories

Activities / Information	Decide how much to obtain	Decide from where to purchase	Purchase material	Receive material	Decide how to store	Store material	Make material available
INPUTS	• Demand information • Re-order policy • Existing stock level • Safety stock level • Inventory constraints • Prod. Spec.	• Supplier listing • Price per supplier • Lead times • Supplier performance history • Price constraints	• Supplier decision • Quantity decision • Price	• Material specification • Quantity ordered • Price • Time specified Purchase Order • Advice Note	• Product location • Storage availability • Quantity to be stored • Prod. Spec.	• Product spec. • Location • Quantity	• Product spec. • Location • Quantity
OUTPUTS	• Quantity decision • Prod. specs	• Supplier decision • Price	• Purchase order	• Decision to accept or return to supplier • Quality test results • Time received	• Product spec. • Location • Quantity	• Product spec. • Quantity stored • Location	• Quantity supplied • Product supplied • From where supplied • Storage availability
MEASURES OF PERFORMANCE	• No. of times out stock • Specific inventory cost • Cost of activity	• Quality of decision • Activity cost • Price obtained	• Activity cost	• Acceptability of material • Timeliness • Activity cost	• Ease of location and acquisition • Activity cost	• Total inventory cost • Stock turnover rate • Storage cost	• Access time • Activity cost



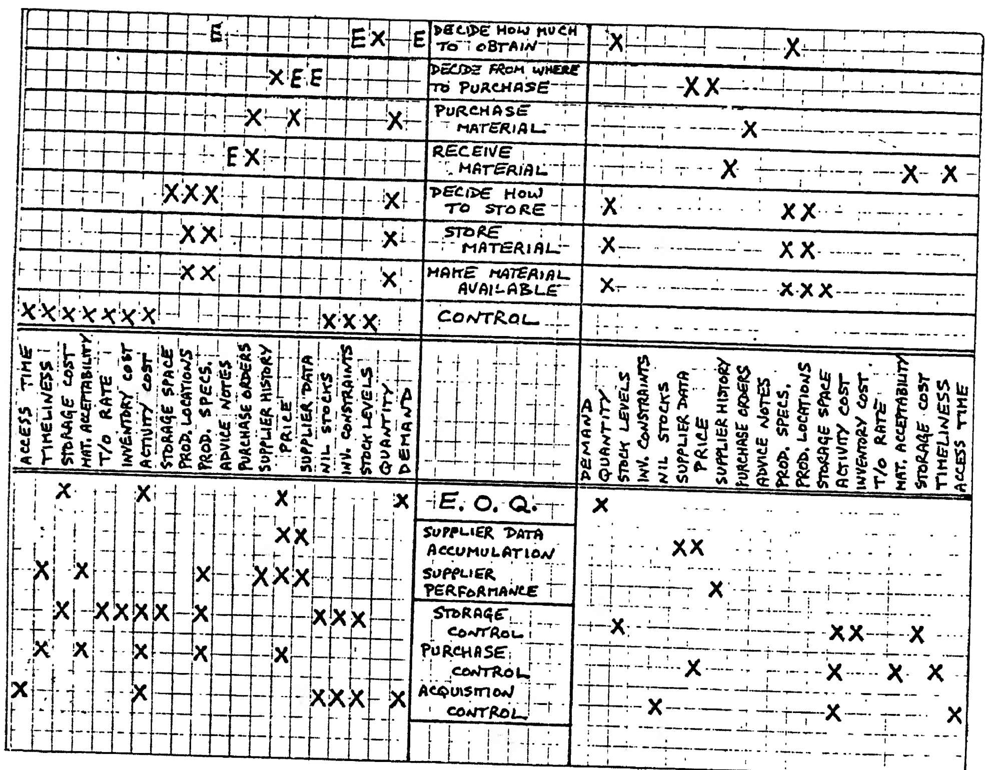
The information categories are effectively 'processed Data' since the meaning is implicit in the use of which the data is put within the activity for which it is support information. Hence the data model is the device which translates information (derived on the basis of its use) to data (which is to be provided as the output of the data-processing network).

Once this stage of the analysis is complete the activity-to-activity information (processed data) flows can be displayed through the construction of the top half of a maltese cross. Figure 14, is the maltese cross developed for the system 'obtain raw materials'.

The next stage is to map on to the bottom half of the maltese cross the existing information processing procedures (I.P.P.s). This is done by identifying the information categories that the input and output data belong to (i.e. through the data models). Within the area of the organisation represented by this model the only I.P.P. that formally existed was an operationsl package that calculated the economic order quantity (E.O.Q.) of material to be purchased. The formula used was:

$$E.O.Q. = \sqrt{\frac{2\ R.Cp}{i.C}}$$

where;
R = Demand
i = Storage Cost
C = Item Cost
Cp = Cost of Ordering



E – Data Source External to 'Obtain Raw Materials' System

Figure 14: Maltese Cross for 'Obtain Raw Materials' System

This package is mapped on to the maltese cross in Figure 14, as shown.

It is apparent from the top half of the maltese cross that much more information than this is required and, since this derivation is based upon the minimum necessary needs, the information provision should be formal. An examination of the crosses in the N.W matrix will identify the support information categories that represent the processed data needed (as opposed to basic or unprocesses data). Here, processing refers to the manipulation, or the putting together, of several elements of data rather than simply the activity of updating. (Stock levels, for example, may involve the assembly of data about several products at several locations or it may be no more than the updating of single items of data without any accumulation).

The specification of 'I.P.P.s to be designed' requires several stages. Firstly the above identification of support information categories needs to be carried out. For each category required, the basic data available from which it can be assembled must be identified (this can be raw data or data which has already been processed). Once this is known the necessary data transformation process can be derived. This data transformation process may then be mapped on to the maltese cross as illustrated below.

X X X
Unprocessed or Basic Data (S.W. Matrix)

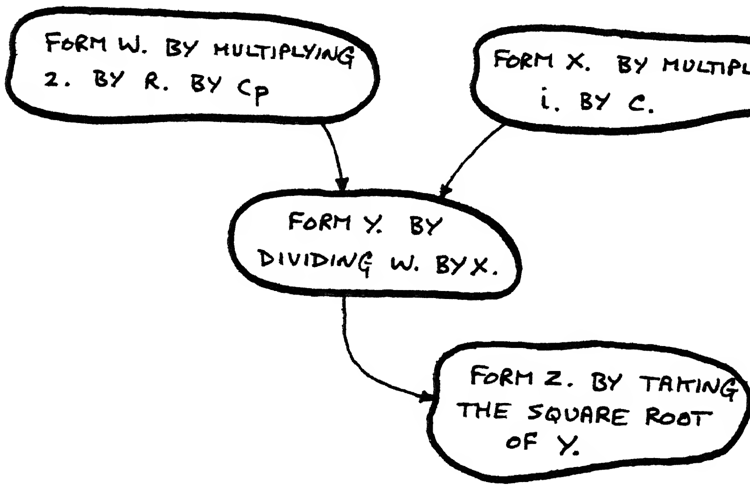
DATA TRANSFORMATION PROCESS
Data Transformation Activities

From N.W. Matrix
X X
Processed Data

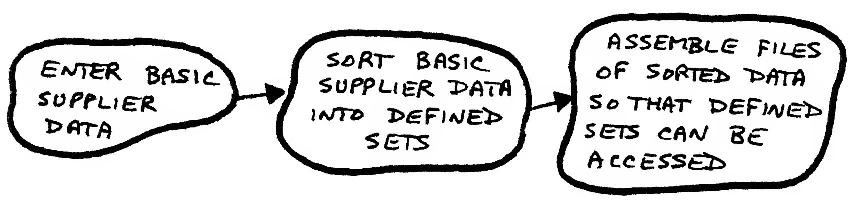
The data transformation process so specified is not necessarily an I.P.P. It may be more efficient (in data processing terms) to group together several data transformation processes to form a single I.P.P. This is illustrated in Figure 14 by two examples. Firstly to do the activity 'decide from where to purchase' it is necessary to have available a listing of supplier data (defined by the data model illustrated earlier). This listing will be assembled from individual data about individual suppliers and it may be necessary to access the listing by supplier, by location or by product. Thus a data transformation process is required to do this assembly in such a way that it can be accessed as appropriate. The decision about where to purchase may also be dependent upon the previous performance of the suppliers in terms of material acceptability, timeliness of delivery, etc. Thus an additional data transformation process is required which assembles this supplier history. An examination of the relevant columns (relevant to both these data transformation processes) in the S.W. matrix indicates that some of the data

elements are common and hence, to avoid duplication of data processing, these two data transformation processes were combined into a single I.P.P. to provide 'supplier intelligence'. A second example is included in the lower half of the maltese cross in Figure 14 in which 3 data transformation processes to do with 'storage control', 'purchase control' and 'acquisition control' were combined with the existing E.O.Q. package to form an I.P.P. - 'inventory control'.

The final stage of the I.P.P. specification, prior to design, is the construction of activity models of the data transformation processes themselves. For the E.O.Q. package the model is obvious enough, i.e.



For the data transformation process 'supplier data accumulation', the model developed was as follows:



Two further activities that it was necessary to consider prior to the design process were 'define what sets are required' and 'decide how to access'. These are not included in the model since they are not part of the data processing. The model for the data transformation process 'supplier performance' was added to this to give the total model for the I.P.P. 'supplier intelligence' illustrated by Figure 15.

So far no decision has been made about how to do these activities. They may be undertaken manually or designed for computer processing. This decision is based upon the relative availability of computing and manpower resources, the costs associated with using either and the preferences of the people concerned.

Returning now to the methodology in general and the relationship of this example to it, everything that has been done so far has been independent of the particular organisation structure in the company concerned. The decisions about information required were made on the basis of the activities within a 'validated' primary task model. The decisions about the design or modification of the I.P.P. network were made on the basis of the efficiency of data processing. The final stage in the methodology is therefore to relate the processed data provided to the needs of the actual managers based upon a definition of their roles within the particular organisation structure. This was done through a mapping of the areas of decision-taking responsibility on to the primary task model and through the resolution of 'island activities'. This stage has already been described in detail earlier and hence will not be repeated here.

Having now described the various stages in this methodology it is worth providing a more detailed summary of the stages involved than given earlier.

METHODOLOGY IN DETAIL

Stage 1

Undertake an issue-based analysis in order to determine what to take to be a primary task description relevant to the situation.

Stage 2

Develop a 'validated' primary task model to whatever level of resolution is appropriate. 'Validation' is an iterative process in which the model may be modified based upon questions generated by the model. Two methods of validation have been found to be useful (other than a general questioning based upon the desirability and feasibility of the activities). These are

(a) determine what the output of an activity would be and look for the existence of that output in the real-world situation. If the

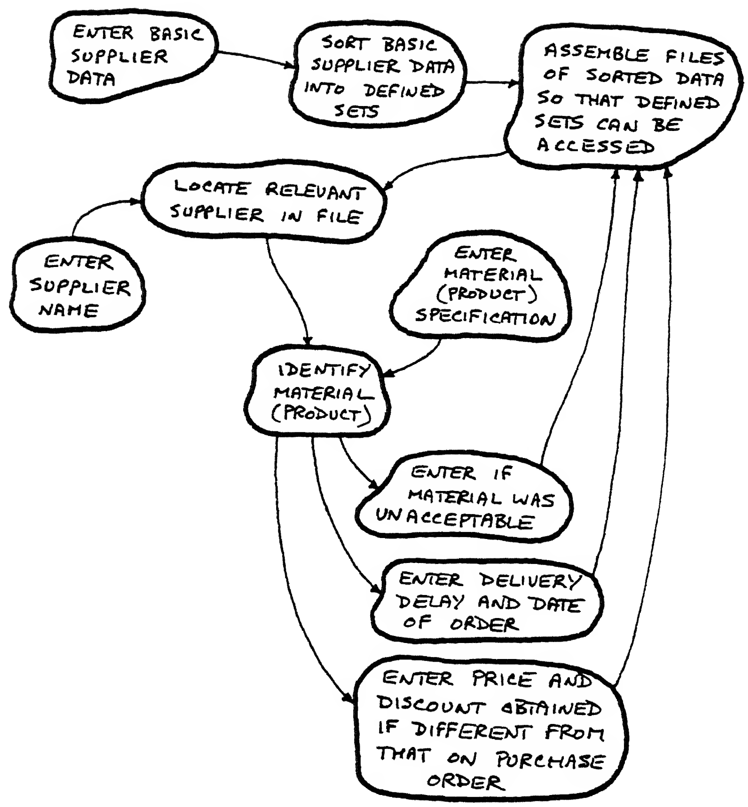


Figure 15: Activity Model for I.P.P. "Supplier Intelligence"

output exists then the activity producing it must exist (eg. a production plan cannot exist without there also being an activity 'plan production').

(b) Through interviewing, develop individual primary task models relevant to the areas of responsibility of the individual managers. A mapping of these individual models on to the overall primary task model will enable validation to be achieved. This method also helps in the final stage of organisation mapping.

'Validation' in these terms means that the activities in the model are legitimate.

Stage 3

Treat each activity in the primary task model as an information transformation process and identify:

(a) The information required as an input to each activity so that the activity can take place.

(b) The information produced (as an output) by doing the activity (but only that that is used as an input by some other activity).

(c) For the control activities, the monitoring information needed based upon a definition of the measures of performance for each activity.

At this stage define each information category in terms of its data content (i.e. by deriving a data model).

Stage 4

Use the results of stage 3 to construct the top half of a maltese cross.

Stage 5

Take each existing information processing procedure (I.P.P.) and identify the information categories that the input and output data belong to (through the data models). Map the I.P.P.s on to the bottom half of the maltese cross.

Stage 6

By examining the support information categories required by the activities in the primary task model (N.W. matrix), identify any ommissions or potential duplication in the existing data processing network by translating requirements (N.W. matrix) into provision (S.E. matrix).

In a 'green field' situation, or where omissions are to be rectified, establish 'data transformation processes' necessary to fulfil provision requirements. Investigate alternative ways of combining these 'data transformation processes' into I.P.P.s to avoid duplications and further omissions in the resultant data processing network.

Stage 7

For each I.P.P. (new or modified) develop the activity model for the transformation of basic, or unprocessed, data into the required processed data. These activities represent a definition of what it is necessary to do to the basic data to provide the support information categories required from the I.P.P. network. Decisions are then required to determine how to do the activities, i.e. manually, by computer, or by a combination of both. It is also necessary, at the same time, to determine how to capture and store the basic data.

Stage 8

Convert the activity information requirements into 'role' information requirements by doing an organisation mapping on to the primary task model.

Note this may have been done already if the method (b) of doing the validation had been adopted.

In Summary

* Stages 1 to 7 determine what I.P.P.s are required, within an efficient data processing network, to provide the essential information requirements of the organisation in total (or in part).

* Stage 8 determines who (in terms of role) needs the particular sets of processed data produced by the I.P.P.s.

CONCLUSIONS

My aim in this paper has been to present methodologies, which make use of the concept of a human activity system, and which I believe are relevant to the analysis of integrated production systems. They represent ways of structuring the thinking about the real world of production or manufacturing and aim to identify ways in which effectiveness can be improved prior to the use of appropriate techniques aimed at improving efficiency. They have emerged from an 'action research' programme, and hence represent methodologies that have been tested in practice. It is my hope that the brief illustrations of use given in the paper are sufficient of provide adequate understanding of the methodologies to result in a critical and constructive debate.

ACKNOWLEDGEMENTS

I would like to express my gratitude to all my colleagues, both within the Department and in the many organisations in which the projects referred to have been carried out. In particular I would like to thank Professor Checkland for a most stimulating collaboration over many years and Ponderosa Industries S.A. who gave me permission to refer specifically to the project carried out within their organisation.

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A CLASSIFICATION SCHEME FOR MASTER PRODUCTION SCHEDULING

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INTRODUCTION

History

Early MRP-systems were developed without recognition of the Master Production Scheduling function. Material Requirements Planning (to become termed later as MRP I) was considered a deterministic mechanism, translating a known demand into planned orders for components and subassemblies-in such a way, that nearly all inventory could be avoided. The question, whether the demand was really *known* was not posed; the demand *had to be known*. This idea was reflected in standard software packages for MRP I, where no decision-support systems for master production scheduling were provided (for example PICS [6]).

The essential difficulty with this type of production-inventory control system is, that there seems to be no handle by which management controls production. On the other hand, the model behind MRP I does not include a number of problems occurring in reality, such as long-leadtime items, capacity shortages, inventory build-up for seasonal demand, and demand-uncertainty.

The concepts of master production scheduling provided an answer to these objections around 1970. When using material requirements planning, all production planning and control actions are derived from the gross requirements specified for end-items (or main subassemblies); these planning numbers "drive" MRP I. As such, they constitute a statement of production. Originally, the values specified for these items were equal to the expected demand. However, the

recognition that a statement of demand is not necessarily the same as a statement of production enabled the creation of a new decision function: the function to establish a statement of production, *based on* the statement of demand, but *not identical to* the statement of demand. The statement of production was called: master production schedule (MPS).

This development from MRP I-theory ultimately led to MRP II-theory, where MRP stands for manufacturing resources planning. In MRP II, materials and capacities are both seen as equally important resources. Furthermore, there exists the acknowledgement that inventories may be useful, both for coping with demand uncertainty and for balancing capacity workload.

Master Production Scheduling

Master production scheduling theory brought *management decision making* back into the production-inventory control system, because it requires an explicit decision on what is going to be produced. Practice was miles ahead of theory, for in many practical situations managers had been trying for long to influence gross requirements of end-items in MRP I controlled production environments. Nevertheless, master production scheduling theory led firstly to a clear distinction between Sales responsibility and Production responsibility. Secondly, it has resulted in understanding the nature of an MPS in terms of MRP I-theory. An MPS is *not* a gross requirement, to be netted against inventory and open orders, but it resembles a *firm-planned order* (cf. Orlicky [5]) where the netting and lot-sizing logic of materials requirements planning is skipped. Thus, *planned inventory build-up* becomes possible for MPS-items. Finally, the development of master production scheduling theory has led to the development of a number of decision-support models, to be discussed at some depth in this paper.
However, the medal has a reverse side: *nearly all problems encountered in production-inventory control are concentrating in master production scheduling in MRP II-theory*. The MPS should be realistic, i.e. it should recognize capacity limitations, material limitations and vender limitations. The MPS should adhere to top-management decisions reflected in aggregate production level, in inventory targets, in production economics, in flexibility to adapt to changes in the market, and in service-levels.

Withing the space of this paper it is impossible to introduce the concept of master production scheduling in full scope. The reader may find a good introduction in Berry, Vollman and Whybark [1].

In the remainder of this paper we shall atempt to classify a number of *proto-problems*, often encountered in master production scheduling. We will extend the concept of master production scheduling to situ-

ations where materials requirements planning is not prerequisite, (such as make-to order) or even not well fitting (such as engineer to order). Next, we will investigate current decision-support models for master production scheduling, and indicate situations where better models are required.
We are certainly not suggesting, that each real-life production situation is characterized by only one proto-problem. On the contrary, the rich variety of real-life situations is generated by the fact that many combinations of proto-problems are encountered in practice!

NATURE OF MASTER PRODUCTION SCHEDULING

Make-to-stock, assemble-to-request, make-to-order, engineer-to-order

In the remainder of this paper we shall frequently refer to a categorization of proto-problems into the above four categories. However, slightly peculiar definitions are employed. *Make-to-stock* refers to the situation, where standard products are manufactured and where the MPS-items are end-items. *Assemble-to-request* refers to the situation, where standard products are manufactured and where the MPS-items are *not* end-items. This is usually the situation, where a lot of options can be attached to each basic type of product. The question, whether the final assembly scheduling is generated by customer orders or by stock-replenishment orders, is irrelevant.

Make-to-order refers to the situation where production cannot be started before the customer order is received. However, when an order is received, it is known completely. The impossibility to start production may be due to several reasons, e.g.
- the customer has to specify the quality
- the customer has to provide drawings and/or materials
- the product is perishable.

The master production schedule (in its extended sense perhaps) consists in this case of a backlog of received customer orders and furthermore of estimates, based on blanket orders, prospects and submitted quotations.

Engineer-to-order differs from the make-to-order situation in two respects: firstly, the engineering activities should be planned and added to the product lead time; and secondly, upon receipt of a customer order, the order is *not* known in detail. Thus, the quotation process should be evaluated and budgetted seperately. The master production schedule (in its extended sense) consists of
(1) fully engineered customer orders, in detail
(2) received, non-engineered customer orders, as quoted
(3) an estimate, based on quoted customer orders and prospects.

Note that this categorization pertains to proto-problems, not

to real-life situations. Many firms belong to two or three categories: e.g. *assemble-to-order,* which is a combination of assemble-to-request and make-to-order.

MASTER PRODUCTION SCHEDULING - BETWEEN PRODUCTION AND SALES

Introduction

On the medium term, master production scheduling should create as much flexibility for Sales as is allowed in the budgets; and in the short term, the MPS often is the most important constraint for Sales. In this section, we shall explore these two aspects. First of all, we shall discuss shortly some techniques to *create* an MPS; afterwards techniques for evaluating *change* are presented.

A tool for creating the MPS: planning bills-of-material

An important input for the master production scheduling function is the expected demand. According to Wight and Landvater [8], p. 13, demand can be categorized into five factors:

1. Sales forecast
2. Production forecast
3. Customer orders
4. Branch warehouse demands
5. Interplant orders.

Production forecasts emerge, when so-called *planning bills-of-material* are employed. A planning B.O.M. can be used to break down a demand forecast for a group of items into a demand forecast for the individual items of the group (cf. Orlicky, Plossl and Wight [4]). The "group" is represented as a *pseudo-item.* The information system should provide facilities for distinguishing planning bills from normal bills, and pseudos from real items. The software should be able to aggregate past demand figures for individual items to the group-level in order to measure the forecasting quality.
The planning bill-of-material technique can be used either in a make-to-stock, or in an assemble-to-request situation, or even in a make-to-order situation. In a make-to-stock situation the number of end-items may become too large to handle efficiently in master production schedule decision-making. Furthermore, forecasting errors may be reduced substantially by employing the planning bill-of-material technique. In this case the pseudo-item consists of a number of end-items. This type of MPS is sometimes referred to as a *two-level MPS*, a "higher level" of pseudos and a "lower level" of end-items. Demand uncertaintly is dealt with by safety stock at the end-item level.

The case of assembly-on-request can employ the planning bill-of-material technique in the same way as above; this means that a pseudo is created which consists of a basic machine-type together with all possible options in certain frequencies. Safety stock is

required again for each option. However, the above "grouping" decision-support software *cannot* be used, because it is senseless to aggregate over various options to be attached to one product. An interesting alternative is to employ so-called *"option-overplanning"*. This means that the frequency of occurrence of the option is slightly overstated in the planning bill-of-material, which results in corresponding increase in stock at all upstream stages.

Furthermore, the planning bill-of-material concept may be used in a make-to-order situation for material procurement (if the material is not provided by the customer). This case is conceptually identical to assemble-to-request.

Finally, the planning bill-of-material can be employed for *disaggregation* of an aggregate production/inventory plan. Such a disaggregation is especially required in make-to-stock and assemble-to-request situations.

Tools for change-evaluation; available-to-promise and lead-time picture

A first tool for the evaluation of a proposed change of the MPS within the accumulative lead-times horizon is the so-called *available to-promise logic.* (cf. Wight and Landvater [3] , p. I22). This logic is relevant for an assemble-to-order situation (or in a make-to-stock calculation in case of stock-out). It calculates at what future point in time a certain MPS-item can be promised to a customer. Especially in case customer-cancellation and/or customer order changes this is a very helpful tool.

Another common tool is the *lead-time picture* of an item. This picture shows the accumulated lead-time for an item, as recursively built up from component lead-times. Thus, if a change is requested 7 weeks from now, the master production schedule can quickly evaluate the items that might be effected. This tool is useful for make-to-stock and assemble-to-request situations. For make-to-order and engineer-to-order, all received customer orders normally can be traced through their network. However, for new orders to be quoted a (standard-item) lead-time picture can be very helpful in make-to-order situations, especially if critical materials are controlled by ordering by means of planning bills (or of statistical inventory control).

A tool for both MPS-creation and evaluation

A major requirement of the MPS is that it should be realistic. Capacity limitations form one of the most serious constraints in this respect. MRP II-theory provides a technique called *rough-cut capacity*

planning (RCCP)[x]. In essence, each entry in each time-bucket in an MPS is multiplied by a standard factor for each critical capacity (without time-offsetting). The standard factors are called: bills of labor. In this way rough-cut figures are computed of the workload implied by each future MPS-period on each critical resource. In this way, RCCP abstracts from lot-sizing, time-shifts, and from current backlogs of workload on these work-centres. The last feature is in our opinion the weakest point of RCCP: especially if the current backlog of a critical capacity is significantly deviating from the normal situation, an adequate decision-support system should at least indicate the current situation.

MASTER PRODUCTION SCHEDULING FOR COORDINATION OF INTER-DEPARTMENTAL WORKFLOW

Introduction

In the previous section master production scheduling was considered from the Sales point of view. The MPS should follow the market while remaining within constraints set by material limitations, capacity limitations and aggregate planning budgets on inventory.

However, two problems still remain: the coordination of products to be assembled and simultaneously the coordination of departments to be loaded in a balanced way. MRP I solves the first coordination problem; MRP II adds the *verification* of constraints but it does not *change* the standard MRP I-logic in any way to improve departmental workload balancing. The only way to change the MRP I-logic is by using the firm planned order.

Input/output Control and MRP II

Nevertheless a technique called *Input/Output Control* (IOC) was developed withing the MRP II theory. The idea is, roughly, to keep the amount of workload in each department at a constant level, and to keep the value invested in each inventory point at a constant level (cf. Plossl and Welch [7]; Bertrand and Wortmann [2] describe essentially the same technique, but they use dynamic norms). Assuming finite capacity, IOC is only possible if orders are not always released according to the advices of the MRP I-logic. But this is only possible without loosing control, if there is some *slack* in the system. This slack may take the form of *planned* time-slack (longer

x The same technique is sometimes called *Resource Requirements Planning* (cf. Wight and Landvater [8]).

average departmental lead-times quoted than in reality) or it may take the form of *planned* inventory (usually implemented as safety stock). Both these forms of slack are not very suited for the purpose of balancing departmental workloads with their capacities. Time slack creates irrealistic lead-time pictures and destroys priority control. Safety stock does not really act as a capacity buffer within MRP, but acts as dead stock generating hot lists upon usage. The fact that workload balancing by means of input/output control requires *aggregate inventories* is not yet recognised in MRP II.

A very important point in IOC is the definition of a *department.* When using software for MRP, there is a natural bias to release orders for all items that are shown in the bill of material. Usually this gives rise to a much too detailed control to handle IOC effectively, as all stages between two items in the bill of material are considered to be departments. Sometimes, the control is too coarse. The better way to do it, of course, is to *choose* departments and real inventory points. MRP I theory does provide the possiblility to "skip" inventory transactions by using so-called *phantom-items* (cf. Orlicky, Plossl and Wight [4]). This is not sufficient, however. In most systems it is not possible to add-up all manhours workload released to one department or to retrieve the inventory value between two manufacturing stages.

Input/Output Control in Make-to-order/Engineer-to-order situations

Nearly the same situation is encountered in the coordinating function of master production scheduling in the make-to-order situation. From a theoretical point of view there is a large resemblance between inventory in the make-to-stock situation and backlog in the make-to-order situation. For both situations an IOC-system can be designed. (cf. Plossl and Welch [7]). Furthermore, backlog in the make-to-order situation may act as a buffer for workload variations in exactly the same way as inventory in the make-to-stock situation. There is only one difference: backlog consists of orders with a due date; therefore the buffer has to be "refreshed" continuously in order to realize an acceptable due-date performance. For inventory, there is no such requirement. This difference makes it improbable that the *same* decision-support systems can be used in both situations.

However, current standard software packages for production control in the make-to-order situation do not provide any support for such a usage of backlogs as buffers. It will be recalled that, in many make-to-order and engineer-to-order situations, the MPS (in this extended sense) is not based on a material requirements planning module. Standard software packages for these situations represent a customer-order by a network of *activities*, where each activity may process some materials, specific for the customer-order (e.g. CAPOSS-E [3]). Waiting times are specified between such activities

but there are *no* standard facilities for defining buffers and for "normal lead times through buffers" *for the purpose of departmental workload control.*

This author was involved in a project in a make-to-order situation where the requirements for distinguishing such buffers was strongly felt. Customers who accepted long delivery times (and therefore allowed for long lead times through these buffers) would benefit substantially in quoted prices!

CRITICAL ASPECTS OF MASTER PRODUCTION SCHEDULING - CONCLUSION

Introduction

In earlier sections we have analysed various techniques for master production scheduling both for negotiations with Sales and for coordinating between departments in order to establish balanced workloads. Several aspects turned out to play a role in these functions, viz. *materials, capacities, time and costs.* In this paper attention is focussed on materials, capacities and time. Now the time-aspect is nearly always important. Therefore master production schedule situations can be distinguished into three types:

- situations where capacities are of dominant importance
- situations where materials are of dominant importance
- situations where both materials and capacities are of equal importance.

Capacities dominant

If changes to the master production schedule are to be evaluated primarily on their capacity consequences, rough-cut capacity planning is an appropriate technique. However, as this technique does assume that the work in process is constant it may give rise to errors in interpretation.

If capacities are dominant in the coordination process, i.e. if inter-deparmental coordination is directed primarily at balancing the workload of the departments in relation to their capacities, then input-output control is principle suitable technique. For the general case, much work has still to be done in order to combine IOC with appropriate inventory control.

Materials dominant

If changes in the MPS are primarily evaluated with respect to materials, these materials may be MPS-items in assemble-to-request situations. Here available-to-promise logic is adequate in combina-

tion with planning bills of material. If long leadtime purchasing items are concerned, a similar technique to rough-cut capacity planning might be employed also. Here too, on-hand and open orders should be considered!

If materials are dominant in the coordination between departments, apply materials requirement planning logic!

Materials and Capacities equally important

In this situation, a conbination of RCCP and IOC should be employed. More specifically, the departmental definitions used in IOC should match the capacities employed in RCCP, in order to get an overview of capacities and materials *simultaneously.*

Acknowledgements

Many of the ideas expressed above were developed in collaboration with W.M.J. Bertrand and J. Wijngaard.

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ON THE DESIGN AND MONITORING OF A MASTER PRODUCTION SCHEDULING FUNCTION IN A MANUFACTURING RESOURCE PLANNING ENVIRONMENT

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INTRODUCTION

During the last decade, the theory and practice of production control have strongly developed under the influence of the availability of high speed computers, on the one hand, and Material Requirement Planning (MRP) as a planning tool for complex product structures, on the other hand. The use of computerized MRP techniques in the late sixties and early seventies triggered a process of reconsidering the structure of the production control system in an organization. This process, which is greatly supported by the American Production and Inventory Control Society (APICS), resulted the definition of an integrated set of basic production control functions and their mutual relationships. Elements in this structure are functions like demand management, production planning, resource planning, inventory control, final assembly scheduling, master production scheduling, material requirements planning, capacity requirements planning, input-output control and shopfloor control. The key element in this structure of production control functions is the Master Production Scheduling function (MPS). Figure 1, taken from Berry et al., 1979, shows that part of the control structure that is directly related to the MPS function. According to the APICS definition, the MPS is defined as follows:
"For selected items, the MPS is a statement of what the company expects to manufacture. It is the anticipated build schedule for those selected items assigned to the master scheduler. The master scheduler maintains this schedule and, in turn, it becomes a set of planning numbers which "drives" MRP. ----". Furthermore: A master schedule item is an item that ----- would be deemed critical in terms of its

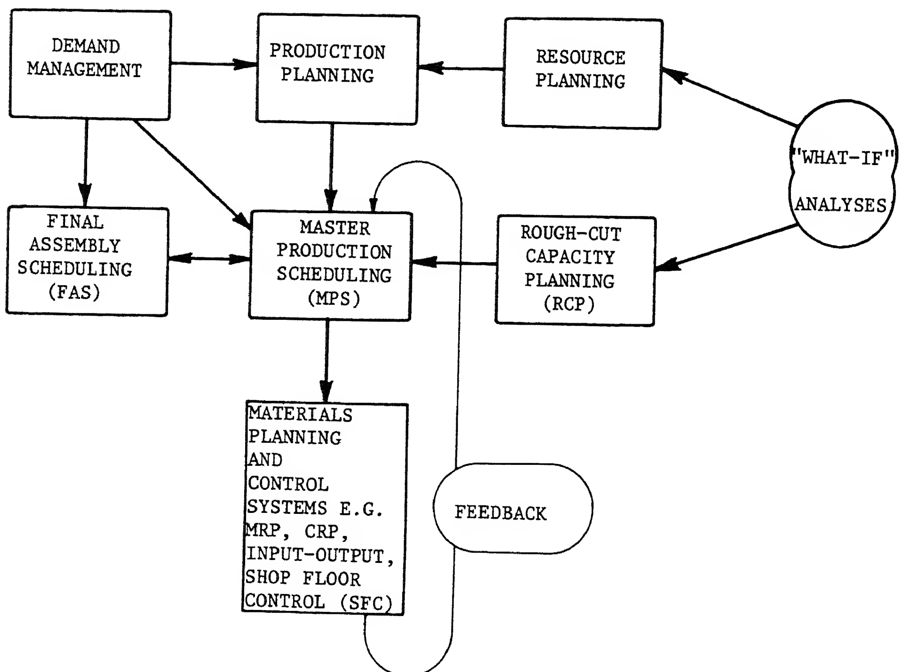

Fig. 1. Relationship of Master Production Scheduling to Other Manufacturing Planning and Control Activities

impact on lower level components and/or resources, such as skilled labour, key machines, dollars, etc.-----" (APICS, 1979).
The MPS is used to solve the conflicts between the market requirements on the one hand, and the production possibilities in terms of available resources and materials on the other hand, thereby taking into account the medium term guidelines set on a aggregate level in the Production Plan. Clearly, solving this conflict implies the balancing of planned levels of customer service, inventory, capacity variation, and capacity utilization. Therefore, in Fig. 1, the MPS function gets input from demand management, final assembly scheduling, rough-cut capacity planning, and a feedback input from material requirements planning. The balancing property in turn implies that the MPS function not only influences the delivery of MPS items, but also, implicitely, capacity loads,inventories, customer service and capacity variations. In fact, in terms of control theory, the MPS planning numbers can be considered as the instrument to exercize control - the control variables or decision variables - whereas customer service, inventory, capacity variation and capacity utilization are the goal variables - or the controlled variables - of the MPS function. In this view, the MPS function controls the production by specifying planning numbers for MPS items and planned capacity for production departments, which serve as an objective for the hierarchically lower level production control functions such as Logistics Control - the function that coordinates the release of workorders to the production departments - and Shop Floor Control.

Based on this view on the place of the MPS function in the production control system, we will determine requirements for the structure of the logistics control system, and the MPS process. Besides, we will develop a procedure for monitoring the performance of the MPS function. For this purpose we will use a conceptual framework borrowed from general control theory. A detailed discussion of this framework, and of its use for developing control and performance monitoring procedures in a production control environment, is given in Bertrand and Wortmann (1981). In the following section we will present a short overview of this framework. Thereafter we will analyse the logistic control function and the MPS decision procedure, and next we present the MPS monitoring procedures. In the final section conclusions are given.

THE CONCEPTUAL FRAMEWORK

We assume that a control problem can be described as follows:
- a *decision function* exists,
- the decision function has *norms*, N(t), for a set of *goal variables*, D(t),
- the decision function can manipulate a set of *controllable variables* (or decision variables), I(t),
- the goal variables are influenced by the controllable variables,

- there exists a set of *environmental variables*, E(t), which influence the goal variables, and which cannot be manipulated by the decision function, but can be observed by the decision function,
- the relationship between the controllable variables and the environmental variables, on the one hand, and the goal variables, on the other hand, is called the *process* to be controlled. This definition implies that the nature of the process *follows* from the definition of the goal variables and the controllable variables,
- if the process is dynamic, there exists a set of *process state variables*, S(t). State variables are defined so that the behaviour of the goal variables during some time interval (t,t+dt) is completely determined by the state at time t and by the values of the inputs I(t) and E(t), during the time interval (t,t+dt),
- the decision function may receive information about the behaviour of the goal variables, the state variables and the environmental variables. The decision function may use, either implicitly or explicitly, a *model of the environmental process*, M_e, in order to produce predictions of future values of the environmental variables. *Explanatory environmental variables*, H(t), which are used as external inputs in the prediction model, may then be defined. If the environmental process is dynamic in nature, then *environmental state variables*, G(t), can be defined: in that case M_e operates on H(t) and G(t). The relationship between H(t) and G(t), on the one hand, and E(t), on the other hand, is called the *environmental process*,
- the decision function uses, implicitly or explicitly, a *model of the controlled process*, M_p, to evaluate possible decisions in the light of the norms, the actual values of the state and goal variables and, possibly, predictions about the environmental variables.

Figure 2 presents the structure of a decision function according to these basic concepts. In the figure, I'(t) represents possible decisions that are investigated with respect to their expected result D'(t), given the state of the process, S(t), and given the expected values of the environmental variables, E'(t). Of course, the "what-if" character of the decision selection routine is used purely for illustration purposes. The decision function could also operate with a simple decision rule acting on E'(t) and S'(t), in which case the model is implicit - thus the models M_e and M_p need not be explicitly used in the decision procedure. However, because in our view the models behind the procedures are the essence of the control, their presence is stressed in Fig. 2.

Generally, the models M_e and M_p will not be perfect: not all variables influencing D(t) or E(t) in reality will be incorporated; their relationships may really be much more complex, the observations of the decision maker with respect to H(t), S(t) and G(t) may contain errors, and finally the decision that follows from the application of the formal decision procedure may not always be completely implemented, for various reasons. In this view on control processes, each of these different sources of uncertaintly constitutes a *disturbance*. The concept of disturbance comprises all factors that affect the predictive quality of the models M_p and M_e. Furthermore, it includes

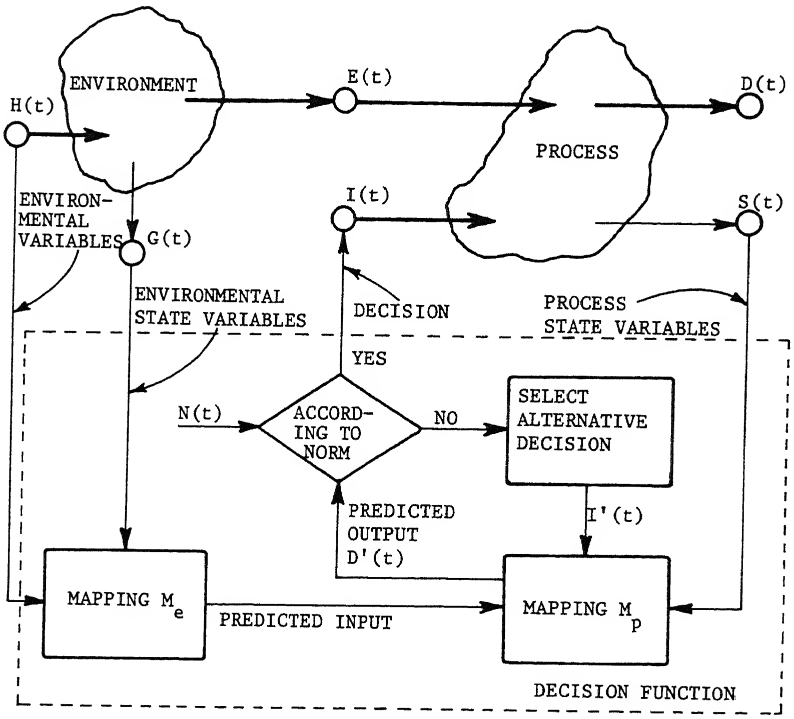

Fig. 2. The conceptual framework of a decision function.

errors in the information available for decision making and deviations that occur in the implementation of decisions. Thus the nature and the level of disturbance faced by a decision function is determined partly by the quality of the models used.

It will be clear that this view of control systems emphasizes the use of a model of the process to be controlled. However in practice a process model will not always be used explicitly in the decision produce itself. Often the decision procedure is a simple, easy to use, routine, with parameters determined from analysis of its performance in practice assuming that the real process is identical to the process model, possibly with some disturbance added to it. Nevertheless such a decision procedure is derived from a process model and it should not be mistaken for the use of an arbitrairy rule of thumb, which is not derived from an explicit process model.

Because this process model in the first place serves as a basis for the design of the decision procedure, we will call it the *design process model* (DPM).

Now consider the situation where a decision procedure is used that has been derived from an explicit DPM. After some time, control performance may deteriorate with time. Therefore, it is important to monitor the control performance, and to be able to diagnose the cause(s) of a change, so that a founded redesign of the decision procedure is possible, if necessary. Changes may be due to external factors, but it may also be due to various causes inherent to the information and the procedures used by the decision function.

In the first place unnoticed changes may occur in the process to be controlled. As a result the quality of the DPM may deteriorate. This can be detected by monitoring the quality of the DPM. The process model quality can be monitored by feeding the DPM with the actual decisions, with the actual values of the environmental and state variables, to produce predictions of the goal variables. By comparing these predictions with the actual values of the goal variables, the error inherent in the model can be determined. An increasing error indicates a decreasing quality of the DPM.

Secondly, the formal decision procedure may contain errors (e.g. mistakes may have been made in the derivation of the decision procedure, which only results in poor control performance under specific circumstances). The existance of such an error can be established by feeding the DPM with:
- the values of the environmental and state variables *as perceived* by the decision maker, and
- the decisions which, for these values, would follow from the formal decision procedure

This results in predictions of the values of the goal variables, which should be compared with norms to evaluate the quality of the formal decision procedure. These norms should have been established in concert with the derivation of the formal decision procedure. If the predicted values deviate significantly from the norms, the decision procedure should be revised (provided of course that the quality of the DPM is sufficient, but this is tested seperately).

Thirdly and fourthly, the quality of the information and command channels requires monitoring. In principle, this can simply be done by direct comparison. However, in most practical situations such measurements will only be available with some delay and on an aggregate level.

Finally, the conditions of the environment should be monitored. This requires that during the design phase the assumptions about the environmental operating conditions for the decision function have been specified, so that adequate monitoring procedures can be designed.

The monitoring activities for the design process model, the decision procedure, the information quality and the command quality can be visualized in one scheme, together with the measuring of the control performance. This scheme is presented in Fig. 3.

From this scheme it will be clear that the presence of an explicit DPM is critical. If such a model is not available, direct evaluation of the performance of a decision procedure is not possible, not when selecting a decision procedure in the design phase, nor during the operation of the procedure. We conclude that selecting a proper DPM is a first requirement for the scientific design and functioning of a decision procedure. In the absence of a DPM, the formal decision procedure will be much more a "guess", or it may not even exist; that is, the decision maker may receive information about the current state of the process, but no decision advice based on a formal decision procedure. The decision maker then has to rely entirely on his mental model of the process.

MASTER PRODUCTION SCHEDULING AS A CONTROL PROCESS

For ease of discussion we consider a situation where a number of products are manufactures to stock, where each product is manufactures in a number of successive phases, with stock points in

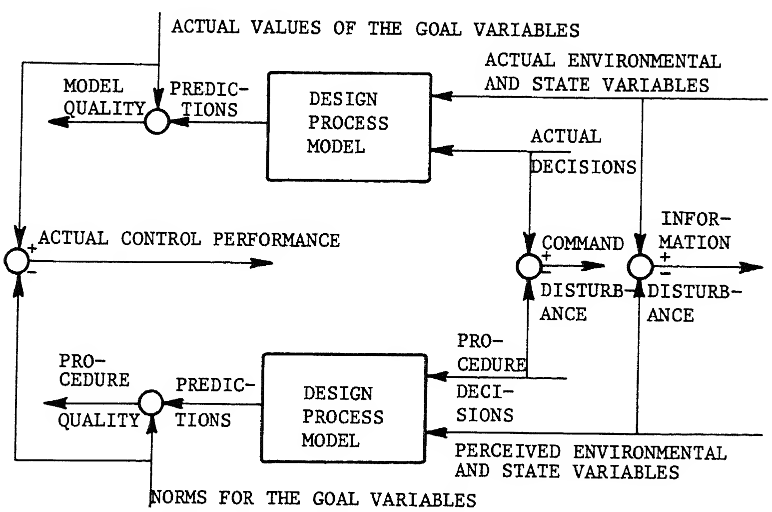

Fig. 3. The monitoring activities.

between, and where production units are defined for each manufacturing phase. An example of such a situation would be a plant with assembly departments, subassembly departments and component manufacturing departments for a range of products. Production is controlled by releasing workorders for the manufacturing of batches of final products, subassemblies or components, and by placing purchasing orders at the suppliers. In broad lines, this situation is shown in Fig. 4.

In recent literature the function Final Assembly Scheduling is defined for the control of the final assembly workorders in reaction to actual customer demand (see Fig. 1). We will not follow this distinction in this paper, as this would complicate the discussion without making a real difference to our subject.

As stated previously, in terms of our conceptual framework the decision variables of the MPS decision function are the set of planning numbers for each MPS item and the planned capacity per production department, and the goal variables are customer service, capacity variations, capacity utilization and inventory levels.

From Fig. 4 it will be clear that the MPS decision function has only an indirect influence on its goal variables. First, the logistics control function translates the MPS-numbers into planned workorder releases and short term capacity variations, and next, shopfloor control influences the actual flow of the workorders through the departments, leading to actual inventories, actual capacity loads and actual deliveries. According to our conceptual framework, the decision procedure of the MPS function should be based on a model of the causal relationships between its decision variable - the MPS planning numbers - and the behaviour of the goal variables. Thus the model used by the MPS decision function should contain assumptions, implicit or explicit, about the decision behaviour of the logistics control function and the shopfloor control function, and the results of their decisions for the flow of products.
(The same goes of course for the delivery control function. For convenience we will concentrate in this paper on the logistics control function).

From the above we conclude that to specify a DPM for the MPS decision function, we first should analyse the impact of the logistics control function on the flow of goods.

Logistics Control

The logistics control decision behaviour is not a standard routine. Although the broad lines of this decision behaviour are quite general, in detail it will differ for each specific production control situation. For the purpose of our paper however, we only need to consider the broad lines. Therefore we will develop a conceptual

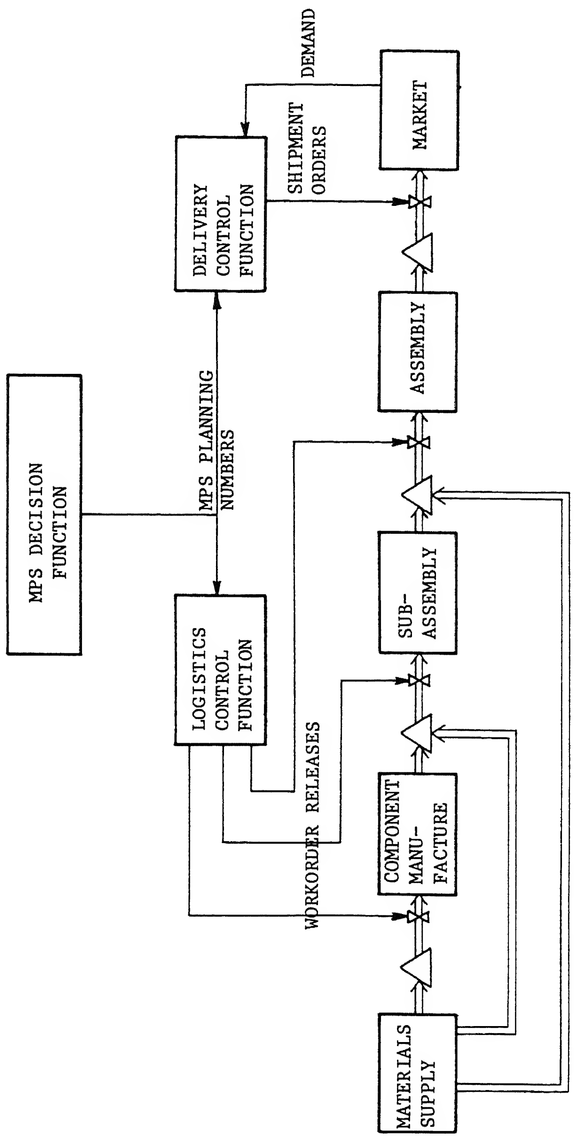

Fig. 4. The global structure of the goodsflow control system for a simple linear production situation.

framework describing the required structure of this control layer between the MPS-decision system and the shop floor control systems, thereby building on the various control activities distinguished in modern literature.

In current literature on production control, (see Fig. 1) MRP techniques are proposed as a general tool for determining planned workorders from the MPS planning numbers. These planned workorders should be checked for materials availability, capacity availability and other constraints on the release of the workorders, modified to harmonize with the possibilities, and then put into action. The main aim of using this technique is to keep inventories as low as possible while maintaining a high level of customer order service.

One of the constraints on the release of workorders is given by the Input/Output Control (I/O Control) of the shop. Input/Output control techniques are used to control the workload of the department or the shop (see Fig. 1). The main aim of this technique is to keep the workload at the level where workorder throughput times per item are according to the norms used in the MPS and MPR procedures. Control of workorder throughput times is crucial, since all production control decision are based on assumptions regarding item lead-times, and workorder throughput times often contribute a considerable fraction of the total item lead-times.

Both of these techniques are a fine tool for their own purpose. However, we think that the decision process at the interface of these procedures should be distinguished separately. The decision process at the interface is extremely complicated, since various kinds of requirements and constraints on the planning and release of workorders should be simultaneously satisfied. Although the general nature of these requirements and constraints is known, the current theory does not contribute much to the structuring of this decision process. Therefore we will have to discuss this process in more detail first.

We assume that MPS decisions are taken each period, and that logistics control decisions are taken a number of times during that period, thus with a higher frequency than the MPS decisions. Consider the situation where the MPS planning numbers have been established and the logistics control starts its activities. First, for each item in the planning Bill of Material (BOM), MRP will calculate the time phased workorders required to realize the MPS planning numbers, given work in process and inventories, batch sizes, yields and lead times. We call these workorders the MRP planned orders. The MRP planned orders may be unrealistic because of material shortages, capacity shortages or surplusses, sequencing constraints on the shop floor due to production economics, etc. This requires revision of the planning numbers before they can be used for workorder release. If these constraints are violated by the MRP planned orders, and there is no slack in the system to cope with these problems, then revision

of the MPS-planning numbers is required (in Fig. 1 this process is indicated by the light feedback line). If this would happen frequently during the period, the control process would become very laborious, which in turn would slow down the speed of the decision process as a whole. Therefore we require that, in general, there should be enough slack in the system, as safety stocks and as short term capacity variations, to avoid the need for revisions of the MPS planning numbers during the period. The safety stocks and capacity slack provisions in the system should be based on this requirement. This also implies that at the start of each MPS decision process, the first thing to do is to make provisions for maintaining these slacks at their required level during each period. Only after this has been done, the real MPS decision process can be started, based on the remaining capacity and materials availability in the system.

Suppose that such a slack controlling procedure exists, and that the slack will be used by the logistics control function to solve the problems caused during each period by the MRP planned orders. (In MRP literature these problems are called "exceptions", which we think is a confusing term). Now we should notice that there are two types of problems. Firstly there are problems that can be solved by changing the *order* in which workorders are released to the shop. For instance, sequencing constraints on the release of workorders, short term material shortages due to unreliable deliveries etc. Solving these problems has only consequences for the planned orders up to a specific point in time. After that point the planning can remain as it was. Consequently, many of these problems will have no impact on the state of the inventories and work-in-process at the end of the period. Secondly, there are problems that can only be solved by shifting planned orders backward or forward in time over the entire planning horizon. For instance, rejects of materials, work-in-process, or inventories, will require the production of one or more items in the preceding phases to be speeded up or slowed down. Solving such a problem will have consequences for the planned orders over the entire horizon. As a result, the total required capacity during the remaining part of the period may deviate from the estimate made at the start of the period. The logistics control function might react to this by immediately changing the capacity and adapting the planned workorders. However, this would create quite nervous control behaviour, whereas it is not entirely clear to the logistics control function whether such immediate reaction is really necessary. For instance it might be that part of the planned production in the MPS has only been included to prevent short term machine idle time; the production may not be really needed on the short term. Another such effect is caused by the difference between the actual deliveries to customers during the period and the forecast made at the start of the period. Here we first have the problem of how to measure such a deviation if deliveries tend to be lumpy. However, even if deviations can be measured, the logistics control function does not a priori know how to react correctly to this disturbance of the planning.

In fact to react properly to these types of disturbances it would be required to restart the MPS decision process. However, this implies that the MPS decision process would be a continuously ongoing activity, which is unmanageable in most practical situations.

This deadlock situation can be avoided by introducing an artificial requirement for the logistics control function. The requirement pertains to the amount of production per department to be realized during each period. The requirement states that production must be equal to the required production, expressed in capacity units of the critical capacity types, determined *during the MPS decision process*. During the period the logistics control function uses this required production level as an input to control the workorder release decisions. This could be done as follows. At the start of each period the required shopload is determined as the product of the required production level and the required workorder throughput times. During the period, workorders are released each time that the actual shopload drops below the required shopload (the shopload norm). *Which* workorders are released, however, is determined by the current status of the planned workorders. The current planned workorders are determined as discussed earlier in this section: starting from the MRP planned orders, the planning is modified to account for the various types of disturbance encountered (the order of the orders is changed, lots may be split up or combined, orders of items are shifted backward or forward, etc.). Each time the shopload drops below the norm, the workorders with the earliest planned release dates are released, until the shopload is balanced again.

In this way the decision making on logistics control level has been split up into two parts:
- to determine *whether* workorders should be released;
- to determine *which* workorder should be released, taking into account external priorities (via MRP), and internal priorities and constraints.

For one of the production phases shown in Fig. 4, the relationships between the various decision functions discussed in this paragraph are presented in Fig. 5.

Master Production Scheduling

We now are in a position to discuss the design process model for the MPS decision function. From the previous discussion it will be clear that in general the MPS decision function should take into account both capacity and materials availability in the system. It will furthermore be clear that the MPS decision function should exercise control at two levels. First, it should guarantee that sufficient slack will be available in the system, so that the logistics control function will be able to cope with the short term disturbances during the period. Second it should determine a MPS that

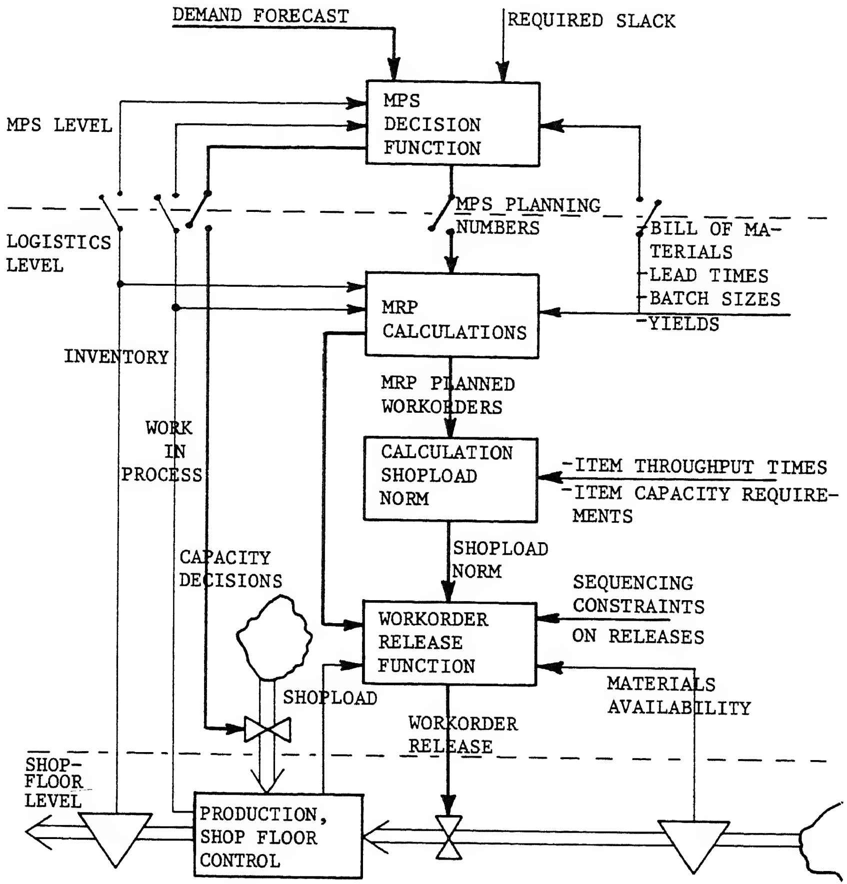

Fig. 5. The decision structure of the logistic control system in relation to its adjacent control levels, for a single production department.

meets the firm's objectives with respect to customer service, inventory costs, capacity utilization and capacity variation. As already mentioned previously, a DPM must be able to predict the response of the system output variables (or goal variables) to the inputs. For our situation, the inputs are the MPS planning numbers and the planned capacity (decision variables), yield deviations, and deviations of

actual capacity relative to the plan (environmental variables). We could also demand that the model predicts the effects of short term disturbances, such as for instance delivery lead-time variations, and changes in the workorder release order relative to the plan. In that case these factors should also be defined as inputs to the design process model. However, it would be extremely difficult to model these effects, whereas we expect that it would not add much to the quality of the predictions. Therefore we will ignore these factors in the DPM. In the monitoring procedure, their effect on the goal variables will materialize as part of the deviations between real values and predictions (see Fig. 2) and thus contribute to the inaccuracy of the DPM. To cope with the effects of this inaccuracy (and other disturbances), a certain amount of slack is maintained in the system (see Fig. 5).

The calculation scheme constituting a possible MPS design process model for this situation is shown in Fig. 6. The scheme is the result of a first effort. We guess that more elegant models can be found. Nevertheless the scheme is satisfactory and it illustrates the use and properties of a DPM. The scheme consists of six basic modules, numbered 1 through 6, which we will now shortly discuss.

- Module 1 consists of calculating the MRP-planned orders over a specific horizon from the MPS planning numbers, using a (possibly aggregated) planning BOM, and taking into account the starting in-inventories and work in process in the system, after having made slack provisions for the next periods.
- Module 2 is used to adapt these MRP planned orders for product reject, yield deviations, and delivery deviations. How these adaptations must be made should be the subject of future research. Various procedures are possible here, which we will not discuss at this stage . Generally the adaptations will be non-existent if the model is used to support the MPS decision process. At that time, future deviations are not yet known. During the monitoring procedure however, these adaptations are necessary because the deviations will have had an impact on the workorder priorities in reality. Module 2 produces the sequence of the planned release workorders. The timing of these workorders still has to be adapted for available capacity.
- Module 3 uses Capacity Requirement Planning to determine the required production (in capacity units) over the horizon per department.
- Module 4 predicts the time-phased shopload in the departments, assuming that the logistics control function will use these required production levels as a basis for shopload control (see Fig. 5).
- Module 5 predicts the time-phased production (in capacity units) on the basis of the shopload and the time-phased available capacity. Depending on the type of shop (conveyor-belt assembly shop, line production shop, job shop etc.) various types of submodels can be used in this module. Discussion of these models is beyond the scope of this paper. Some knowledge is already available on

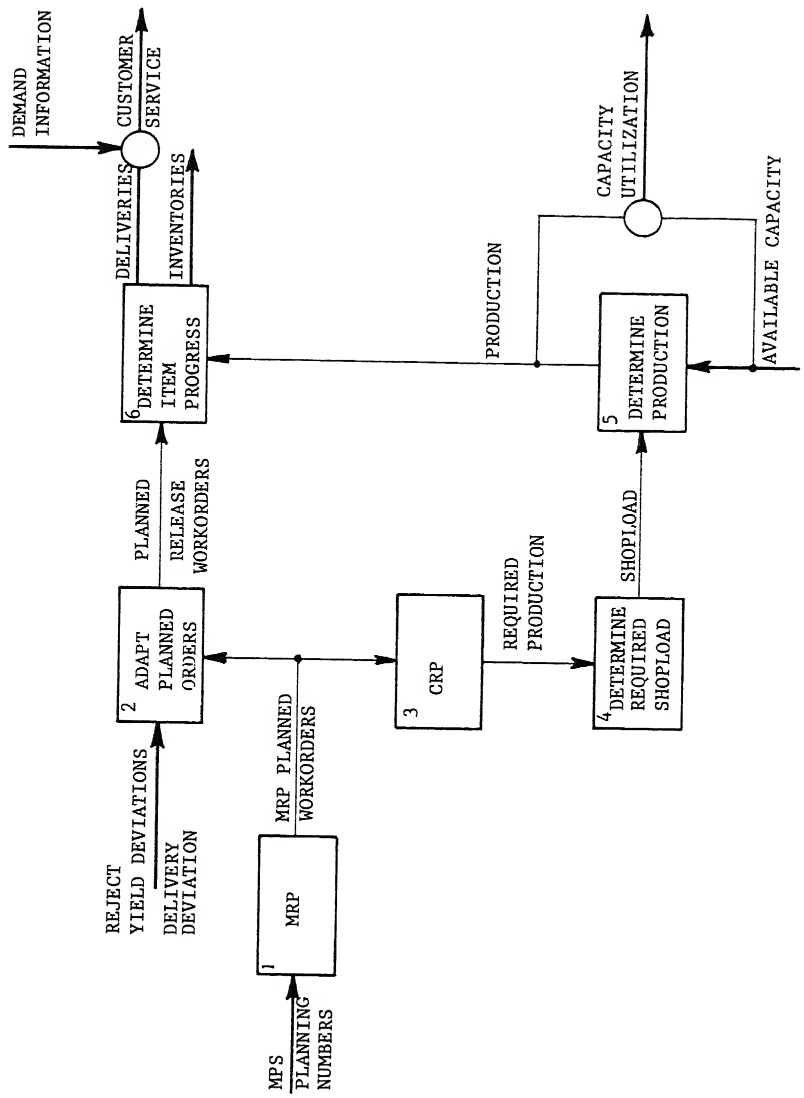

Fig. 6. The flow of calculations of the proposed MPS design process model

this subject (e.g. Solberg, 1981). However, much research is still required here.

- Module 6 uses the predicted production per department to determine the timing of the workorders, which sequence is given by the planned release workorders produced by module 2. Module 6 also yields predicted time-phased deliveries, and predicted inventory levels.

From the inputs and outputs of this set of modules the predicted values of the goal variables can be easily determined. The predicted capacity utilization follows from the predicted production and the available capacity, the customer order service follows from the customer order forecast and the predicted deliveries of end-products. Predicted inventories are directly available from the model, whereas capacity variations are directly related to the input variable "available capacity".

Suppose that the MPS decision procedure uses this type of DPM in a "what if" mode to predict the outcomes of possible configurations of MPS-planning numbers and capacity statements. Then the predicted outcomes should be evaluated in two respects:

- firstly, as widely stated in MPS literature, the MPS planning numbers must be realistic, that is, the time-phased deliveries of MPS items predicted by the model must be equal to the MPS planning numbers that served as an input to the model. Obviously, if the predicted deliveries are not equal to the delivery norm (the MPS) that drives the system, then the delivery norm is unrealistic (provided of course that the model is correct).
  We see that the use of an explicit DPM enables us to find an operational criterion for the requirement "the MPS must be realistic". With the usual techniques for evaluating a possible MPS, this is a problem;
- secondly, provided that the MPS is realistic, the predicted value of the goal variables must be checked against the firm's policy regarding inventories, capacity utilization, capacity changes and customer service. An unacceptable predicted output leads to changes in the MPS or in the planned available capacity until a satisfactory combination is found. Of course, it may (and often will) happen that no combination can be found that exactly matches the firm's policy. Then, the best possible combination is selected, which results in specific deviations in the planned behaviour of the goal variables from their medium term norms. When evaluating the real performance of the control system afterwards, planned deviations should be distinguished from unplanned deviations, because different action may be required to reduce each of these types of deviation.

THE MONITORING PROCEDURES FOR THE MPS DECISION PROCESS

The best model available for the "what if" analysis in the

MPS decision procedure is of course the DPM itself. However, in some situations this model may turn out to be too complex (too computer time consuming, too time consuming, or too difficult to handle in an interactive mode). Then, a simpler model may be used for the interactive "what if" analysis during the decision process. The detailed DPM can be used then each time after the decision has been taken, to check the quality of this decision. The assumption here is that the DPM is a correct representation of the controlled process. This checking process we called earlier "monitoring the quality of the decision procedure" (see Fig. 2). This process is shown in the lower part of Fig. 7. By monitoring the quality of the decision procedure after each MPS decision, serious errors in the decision procedure can be identified early, which may result in timely and adequate adaptations. Thus, this monitoring process creates a feedback-loop that maintains the quality of the decision procedure, relative to the DPM. Because this monitoring process can be performed off-line to the decision process, detailed and time consuming calculations are no problem since there is no severe time pressure on obtaining the results.

Finally, the quality of the DPM must be monitored. This is done at the end of each period, before the next MPS decisions have to be taken. Because the MPS planning numbers constitute a rolling schedule

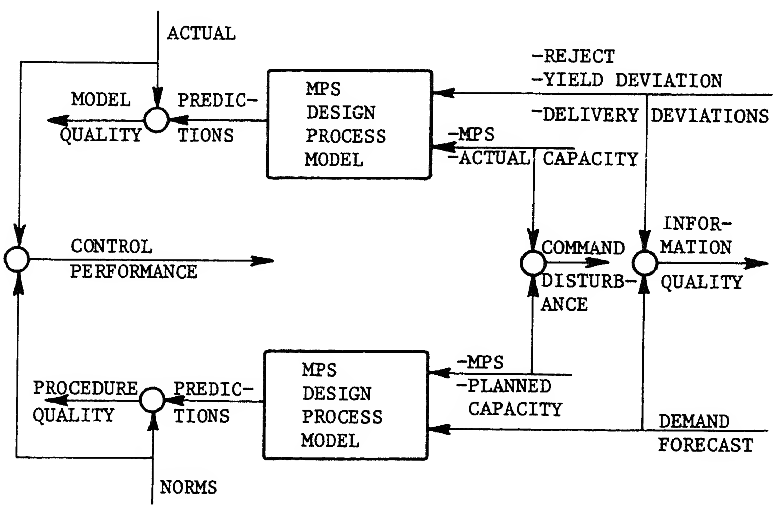

Fig. 7. The monitoring scheme for the MPS decision function. The predictions refer to the goal variables Utilization, Capacity, Customer Service and Inventory.

which is updated at the start of each new period, only the one-period ahead prediction over the past period can be used to monitor the DPM. For each item and for each production unit, the predicted production and inventory based on actual values of the input variables are compared with the actual outputs. This process is shown in the upper part of Fig. 7. Analysis of the differences between prediction and reality may reveal deficiencies in the DPM, which may lead to timely adaptations of the model. Thus, this monitoring process creates a second feedback-loop that maintains the quality of the DPM relative to the reality it represents.

CONCLUSIONS

In this paper we have analyzed the Master Production Scheduling decision function and the Logistics Control Function from a control point of view. First, we have presented a conceptual framework, borrowed from general control theory, for structuring production control decision problems. The central point in this framework is the use of a formal model of the process to be controlled - a design process model. We have applied the framework to the analysis of the above mentioned functions, leading first to requirements for the structure of the Logistics Control function. Then we have identified a design process model for the MPS decision function, and from this we have determined the global structure of the MPS decision procedure. As a result we could operationally formalize the statement that "a MPS must be realistic". Finally we have identified the monitoring procedures both for the MPS decision procedure and the design process model.

This paper once more reveals the importance of design process models for the design of control systems. However, much work still has to be done in applying these ideas to more complicated situations and in testing them in various practical situations. Nevertheless, we think that our results can serve as a firm basis for the design of MPS decision procedures. At the moment we are engaged in such a design process in practice.

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IMPROVING MANUFACTURING EFFICIENCY WITH BETTER LOGISTICAL CONTROL

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INTRODUCTION

Manufacturing efficiency has too distinct aspects: the procedural aspect that deals with the input-output relations of the manufacturing process and the logistical aspect that deals with the question of what item to manufacture in what quantity and at what time. The latter aspect is part of the overall logistical control that governs the operational planning of every company.

Several field studies* of recent years suggest that the logistical aspect of manufacturing efficiency still offers significant cost saving potentials which, in many cases, clearly exceed the cost saving potential of the procedural aspect of manufacturing efficiency (figure 1). Thus these studies seem to confirm that the logistical control of a company and the design of efficient tools for this purpose still are what Drucker once called "the economy's dark continent"**.

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* NCPDM (1978): Measuring Productivity in Physical Distribution - A $ 40 Billion Goldmine, National Council of Physical Distribution Management, Chicago, Ill. 1978.
Teske, H. (1979): Vorratswirtschaft in Fertigungsbetrieben - Ergebnisse einer Umfrage, Frankfurt 1979.

** Drucker, P. (1962): The Economy's Dark Continent, in: Fortune, Vol. 65, 1962, pg. 103 ff.

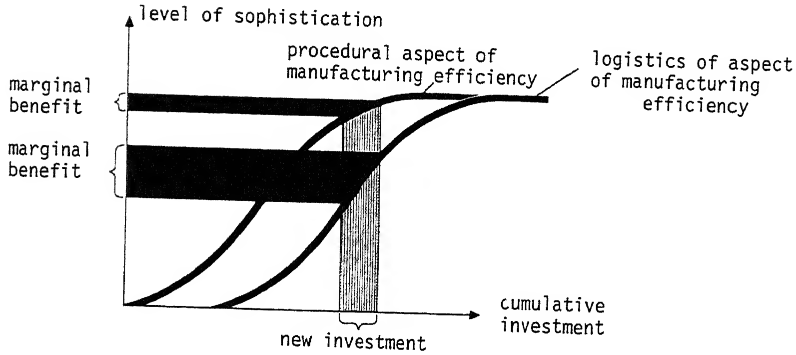

Figure 1: Comparison of marginal benefits of new investments in the procedural aspect and in the logistical aspect of manufacturing efficiency*.

Concentrating on those industries that predominantly have to manufacture for stock and not to firm client order (like e.g. most of the producers of consumer goods) the logistical aspect of manufacturing output per period, the sales volume per period, and the inventory levels in a fashion that best balances total cost incurred and overall customer service generated. The system governing this control process is, as a rule - even in a company with only a few and simple product/market segments - highly complex and typically contains a number of crucial non-linearities. Very early therefore, the use of simulation techniques has been proposed for the analysis of this aspect of manufacturing efficiency. Simulation techniques have also been suggested for use in ad-hoc usable decision support devices that are applied in real companies.

This paper describes how the potential savings that are linked to the logistical aspect of manufacturing efficiency could be exploited more systematically with the help of a simulation model. Our remarks on model conceptualization, validation and implementation will be based on a model project developed and implemented at the Betriebswirtschaftliches Institut der Universität Stuttgart. The model describes the real world problem of a concrete company.

2. THE COMPANY

The BAMA-Werke Curt Baumann (BAMA) in Mosbach, Germany are one of the leading producers and marketers of shoes, insoles and socks in Europe. Sales are approx DM 120 million per year (1981)

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* A. T. Kearney GmbH (1981): Manufacturing Efficiency, unpublished paper, Stuttgart 1981.

generated by roughly 1.000 employees. BAMA operates one main factory and two small subsidiaries in Germany and Austria.

The production of shoes is almost completely based on firm client orders. Customer service in terms of goods' availability and delivery time are no major success factors in this product segment: clients typically place their orders for summer shoes in winter and, conversely, for winter shoes in summer thus allowing enough time for all procurement and manufacturing processes. Except for balancing the somewhat seasonal demand pattern there is no significant need for investment in safety stocks or flexibility stocks.

The production of insoles and socks is, by contrast, almost completely based on demand forecast and on the need to maintain certain strategic stock levels of finished goods. Customer service in terms of goods' availability and delivery time is an important success factor in this product segment and may, at certain times of the year, well override price and quality. In addition to the short-term fluctuation of market demand there is a strong seasonal pattern adding to the need for stock investment. Even on an aggregate level monthly sales (i.e. order entry) may vary by as much as $\pm$ 50% relative to the average month. Deliveries typically fluctuate even more (figures 2 and 3). The extent to which the delivery pattern deviates from an attempted constant monthly production output explains the great need for seasonal buffer stocks. Figure 4 shows the seasonal pattern of the total stock of finished goods i.e. including the seasonal element, the safety element and the technological element (resulting from batch manufaturing etc.). On the average the stock of finished goods lasts for some 50 work days.

Given the importance of high customer service levels to the market success and of low total manufacturing and inventory holding costs to the financial success the proper planning of manufacturing output, delivery volumes and stock levels - i.e. the logistical aspect of manufacturing efficiency - becomes the crucial problem of the company's operation. Operational goals of the firm are a stock of finished goods that lasts for 20 days (seasonal component excluded), a delivery delay of 24 hours for goods that are ordered for current sales, production in large lot sizes, and a continuous production output.

Historically BAMA has been using fairly elementary planning techniques combined with high safety margins in inventory at all levels. Owing to an increased cost sensitivity and to the ever growing importance of customer service levels the company has welcomed the idea of participating in a comprehensive project aimed at designing an EDP-Supported Simulation model that would help planners to improve the quality of their decision in the logistical aspect of manufacturing efficiency.

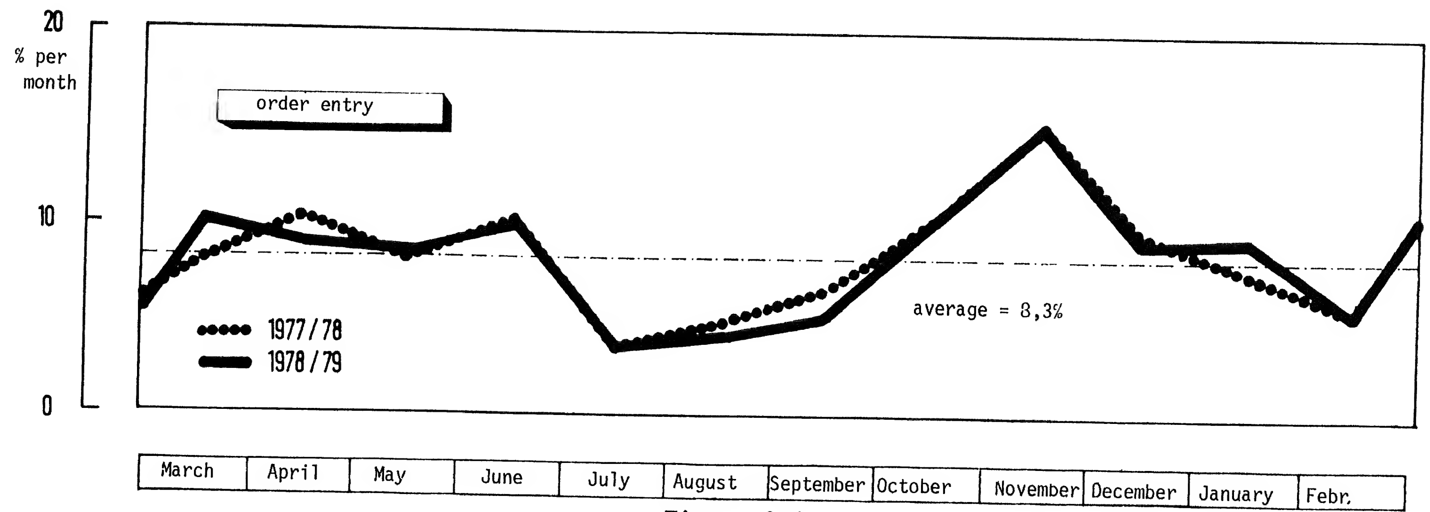

Figure 2.*

* Figures 2-7 are taken from Waldraff, A. (1982): Das logistische Regelfeld "Absatz-Bestände-Fertigung", Frankfurt 1982.

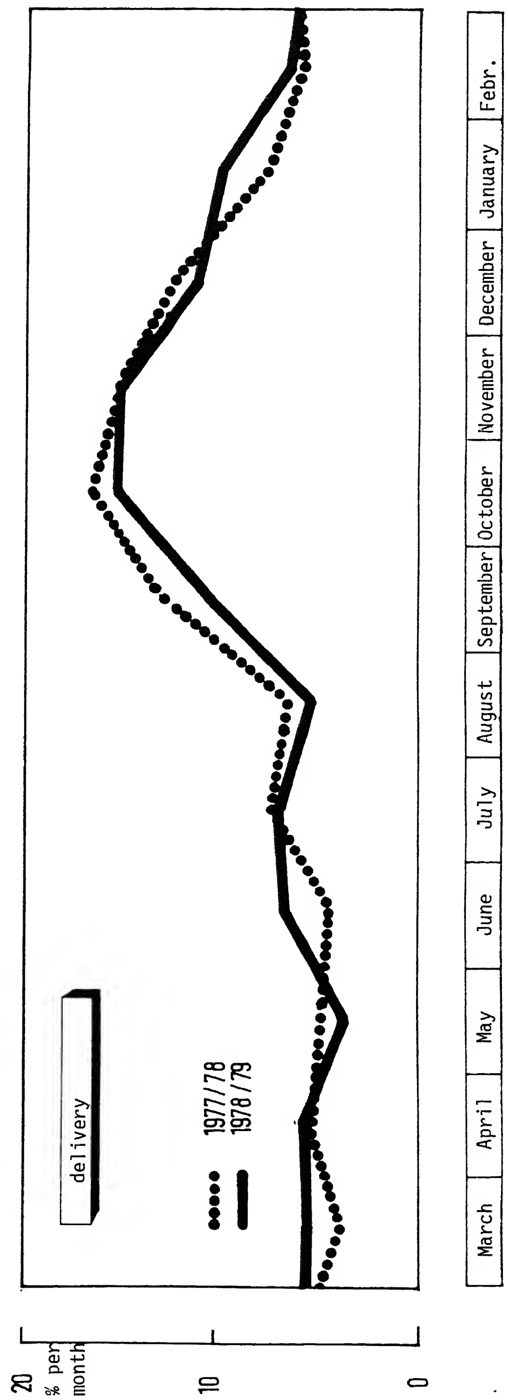
delivery
1977/78
1978/79
20
% per month
10
0
March
April
May
June
July
August
September
October
November
December
January
Febr.

Figure 3.

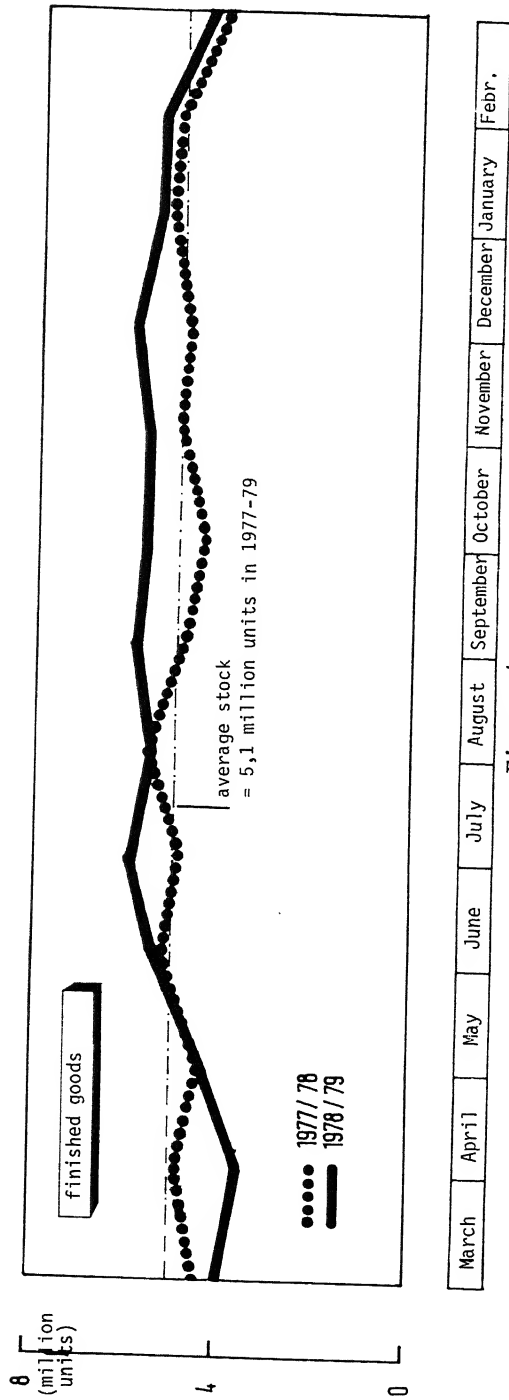
finished goods
1977/78
1978/79
average stock
= 5,1 million units in 1977-79
8
(million units)
4
0
March
April
May
June
July
August
September
October
November
December
January
Febr.

Figure 4.

3. THE MODEL

Following the arguments which have first led Simon* to applying the principle of feedback mechanisms to this kind of real world problem we have chosen System Dynamics** as a method for modelling the logistical aspect of manufacturing efficiency at BAMA.

The model has been developed in a close communication process between model users and model builders. Four iterations (i.e. four completely revised model designs) were necessary in order to achieve the mutual understanding among the team-members concerning structures, flows and decision rules and their representations in the model. This process has taken three years altogether.

a) OBJECTIVES OF THE MODEL

The particular objectives of the model are:

- to identify areas within the firm and its markets that seem to be relevant in order to understand the logistical aspect of manufacturing efficiency,
- to analyse changes in systems behavior caused by disturbances in the market or by decisions taken by management, and
- to formulate policies for improving the real world systems behavior in terms of performance.

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* Simon, H.A. (1952): On the Application of Servomechanism Theory in the Study of Production Control, in: Econometrica, Vol. 20, 1952, pg. 247-268.

** Forrester, J.W. (1961): Industrial Dynamics, Cambridge, Mass. 1977.

b) STRUCTURE OF THE MODEL

The model structure includes the production process (which is devided into three phases), capacity control, material control and man power control. It also includes all relations of the firm to its labour-, machine-, tool-, and material-markets, to the extent they are relevant for operational planning. The basic flow diagram is illustrated in figure 5.

c) BEHAVIOR OF THE MODEL

After validating the model with real world data and experiences from middle level and upper level managers the model was used for a comprehensive series of tests, including a constant demand, a sudden jump in demand, a large unexpected order, increasing and decreasing demand, a flop in product innovation, a too optimistic sales forecast, seasonal fluctuations and short-term random fluctuations in the flow of orders. Also specific management policies were tested in order to identify changes in model behavior.

In figures 6a-f a number of selected test results are illustrated.

As suggested by Zahn* and others one of the first tests is the verification of model stability starting from a homogeneous set of initial variables. Altogether model stability has been established for a 10-year horizon.

A sudden 10% increase of demand is quite realistic in this product-/market segment. All rates in figure 6b are given as ratios of the current value and the respective initial value. The lead-time of production planning is some 4 weeks. Production rates, therefore,

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* Zahn, E.: Validierung von SD-Modellen, unveröffentlichtes Manuskript, Stuttgart (ohne Jahresangabe).

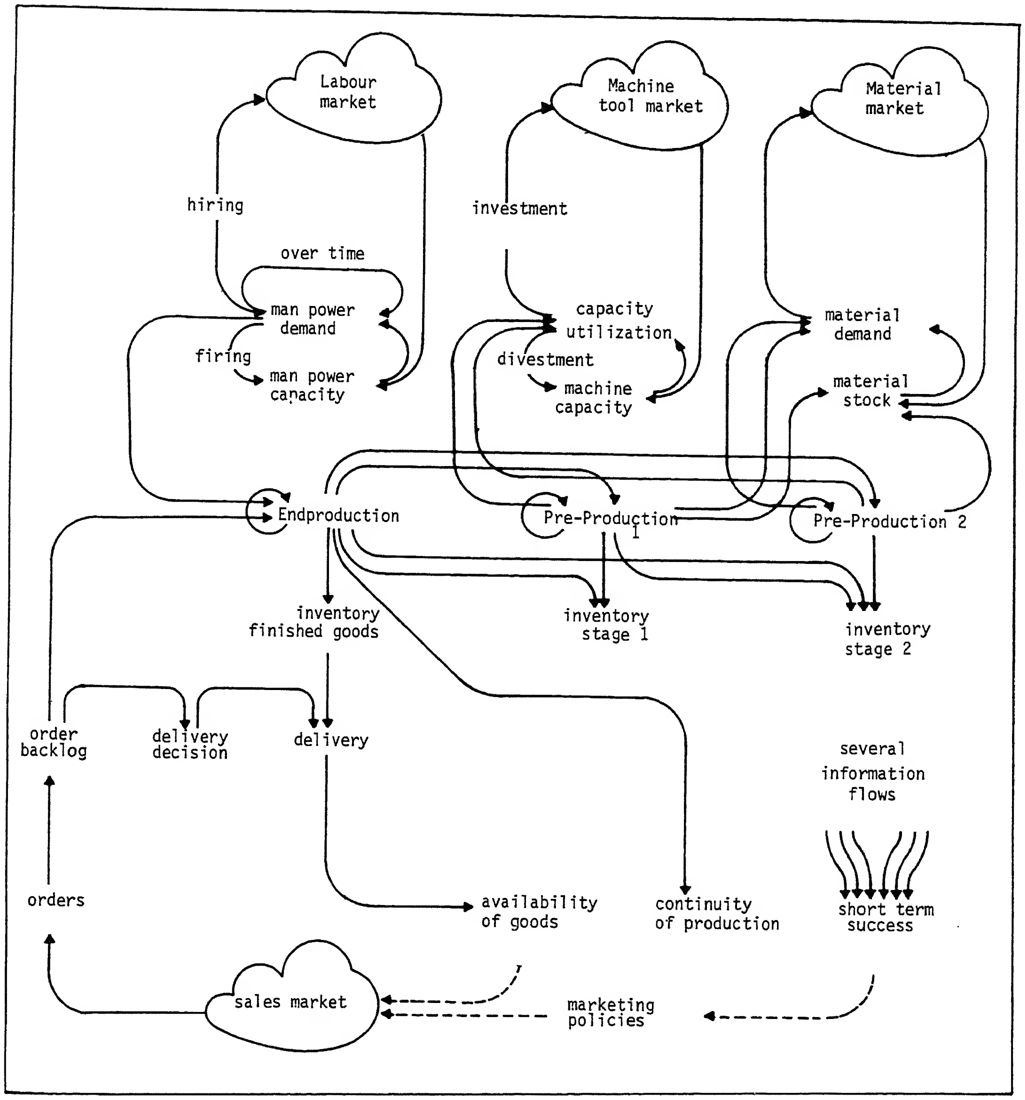

Figure 5: Basic causal diagram of the model.

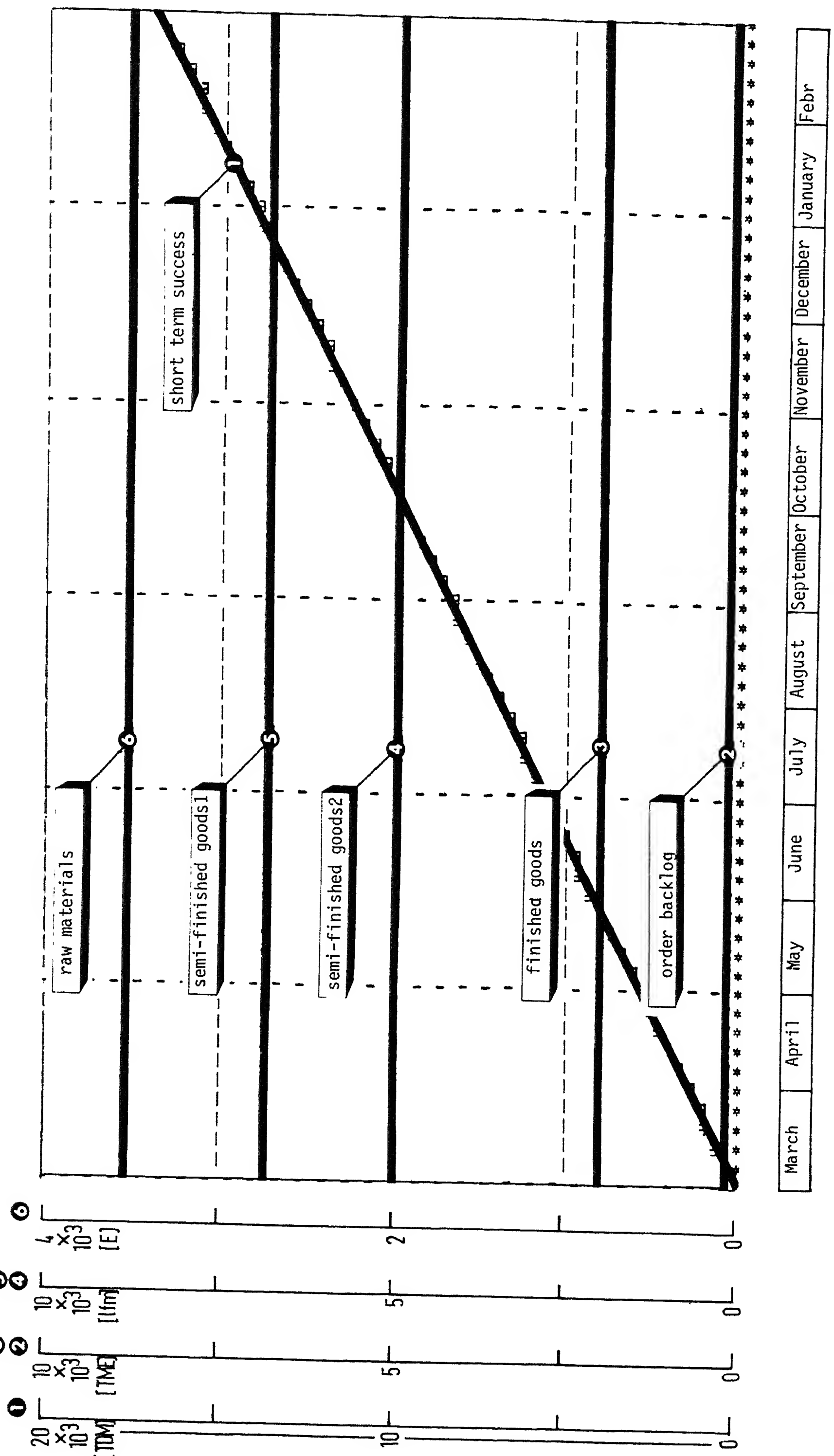

Figure 6a: Dynamics of important level variables with stability conditions.

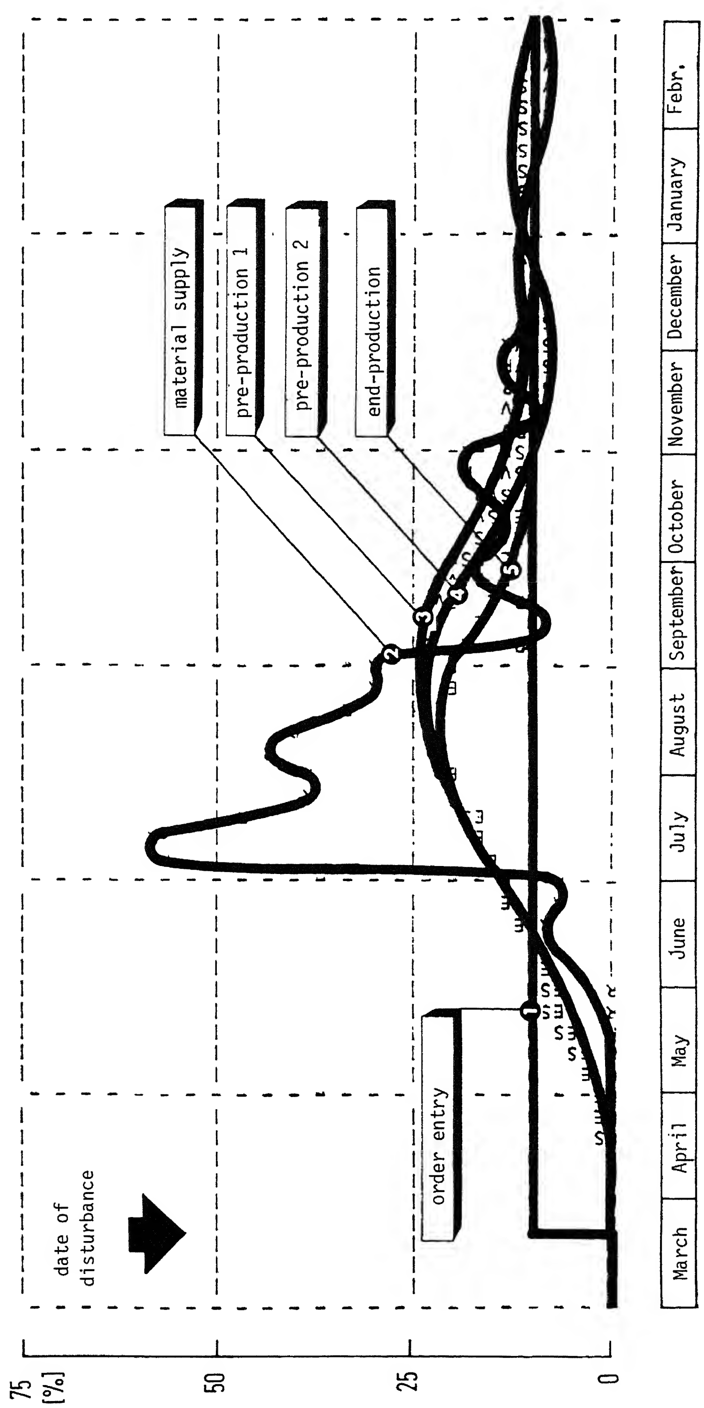

Figure 6b: Response of production rates to an unexpected demand jump of 10%.

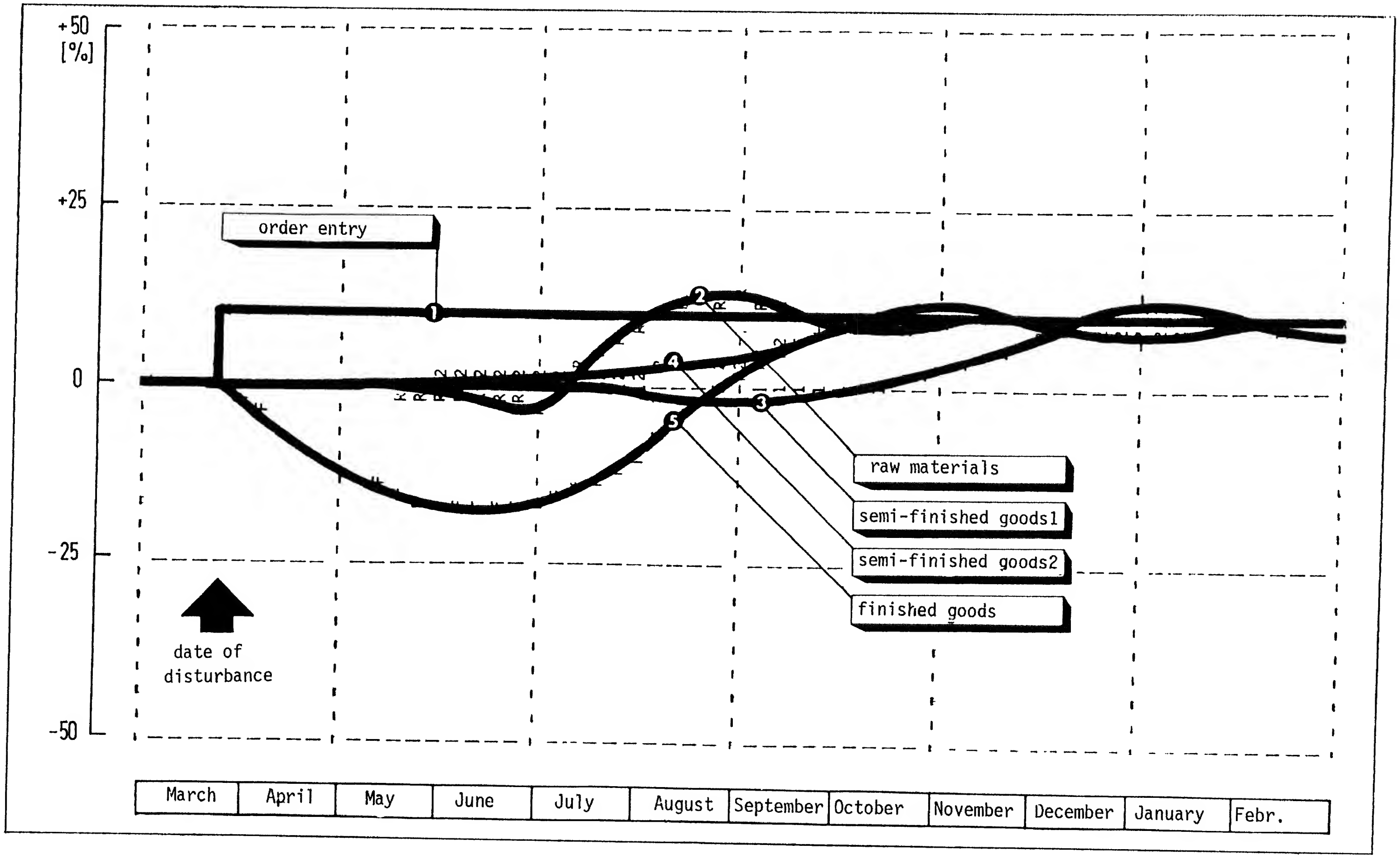

Figure 6c: Response of inventories to an unexpected demand jump of 10%.

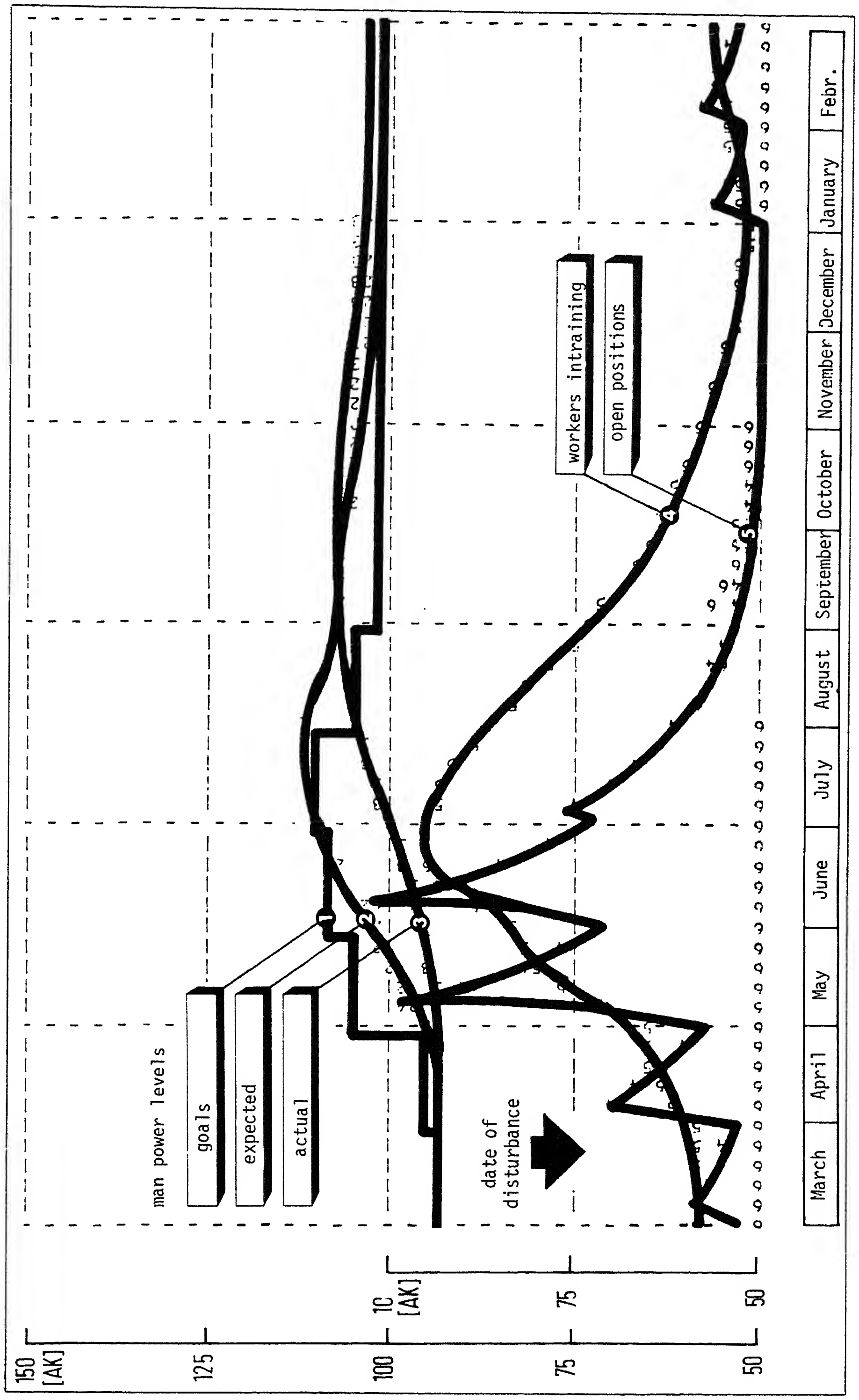

Figure 6d: Changes in manpower capacity after an unexpected demand jump of 10%.

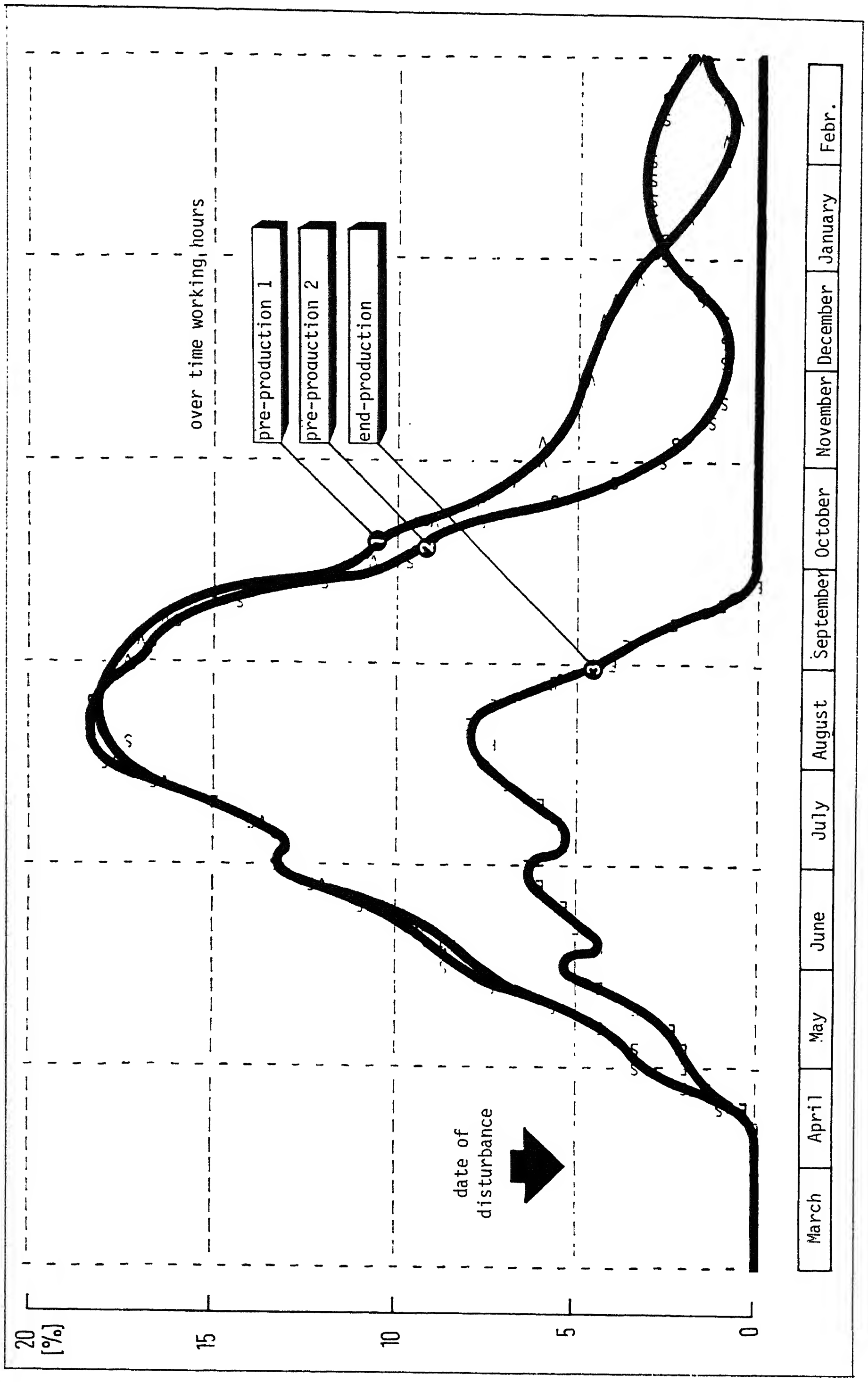

Figure 6e: Overtime working hours after an unexpected demand jump of 10%.

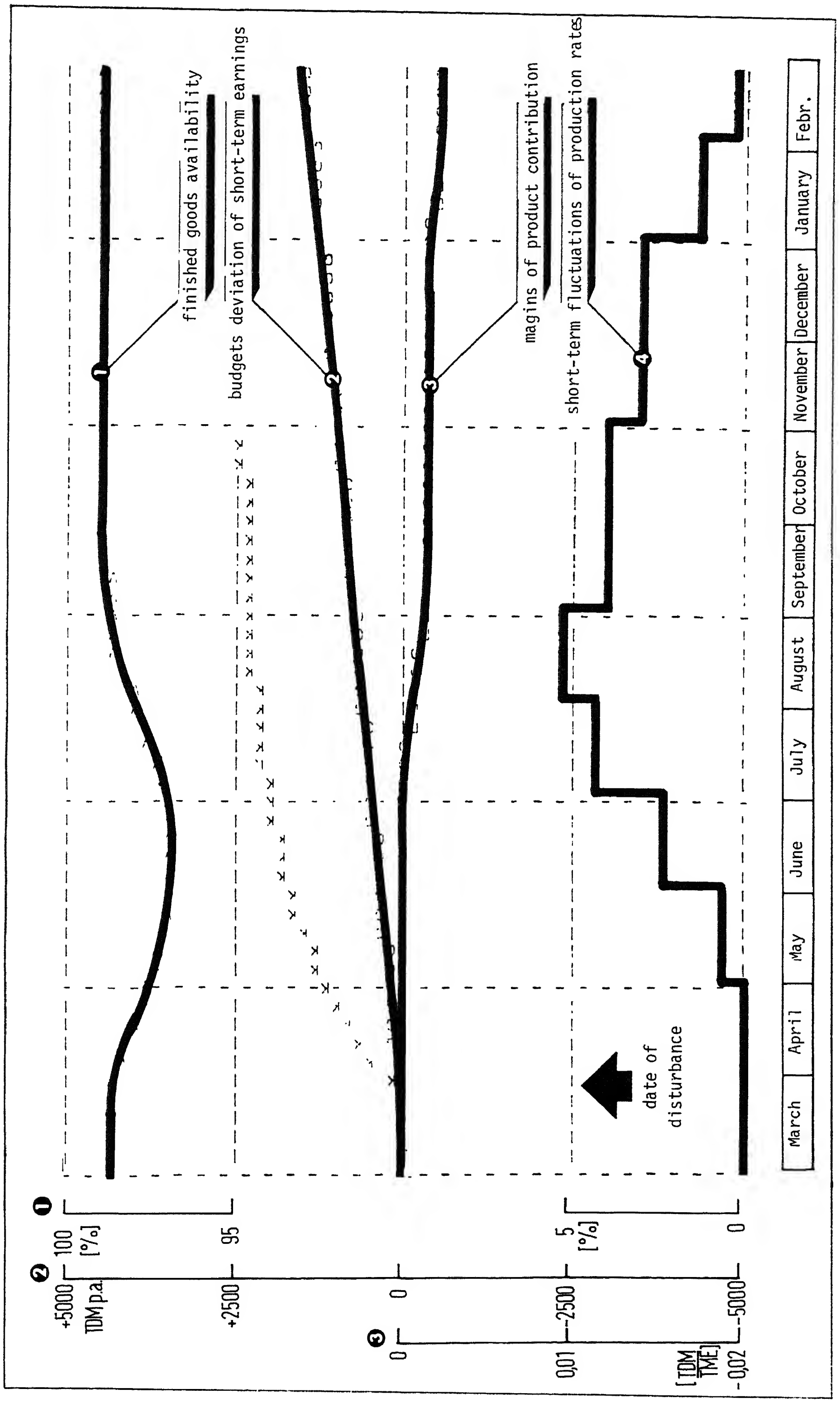

Figure 6f: Development of short-term goals after an unexpected demand jump of 10%.

start to increase only at the end of April in response to the demand jump in mid-March. The inflow of raw material is delayed even more because of the procurement lead times which average too months for the company. In line with the greater response time of the raw material inflow also the extent of deviation of this variable is far greater than the changes of the (in-house) production rates. All rates stabilize in line with the new higher demand level only after some 12 months.

Figure 6c illustrates the corresponding development of the various inventory levels. Given the long response time of e.g. the finished goods inventory it becomes quite clear how difficult (and possibly misleading) management actions may be that are based on inventory management techniques (e.g. an order-point routine) alone and do not assess demand as well and, last not least, the typical dynamical behavior of the different variables involved.

The increased production output requires a higher level of personnel in the plant. Thanks to a comporatively flexible situation of the regional personnel market BAMA does not have great difficulties to adjust its capacity of (mostly female) workers within a reasonably short time of some six months. Figure 6d shows the variables governing this process. Nonetheless quite some overtime is necessary in the plant for about seven months after the unexpected demand jump as illustrated in figure 6e (viz. figure 6d for the corresponding production rates).

As a result of the unexpected demand jump many operational indicators begin to change as depicted in figure 6f. Most important to the customer service level is the drop of finished goods' availability during the five months following the sudden demand stop. Short-term earnings go up, of course, but are slightly injured by the overtime costs. The contribution margins of products go down slightly. The short-term fluctuations of the production rates reach their critical values ($\pm$ 5% change from one month to another) about five months after the disturbance has ocurred.

These are just examples of the model output for the comparatively simple test of a 10% step of market demand. Based on this and many more tests a number of recommendations were developed and accepted by management.

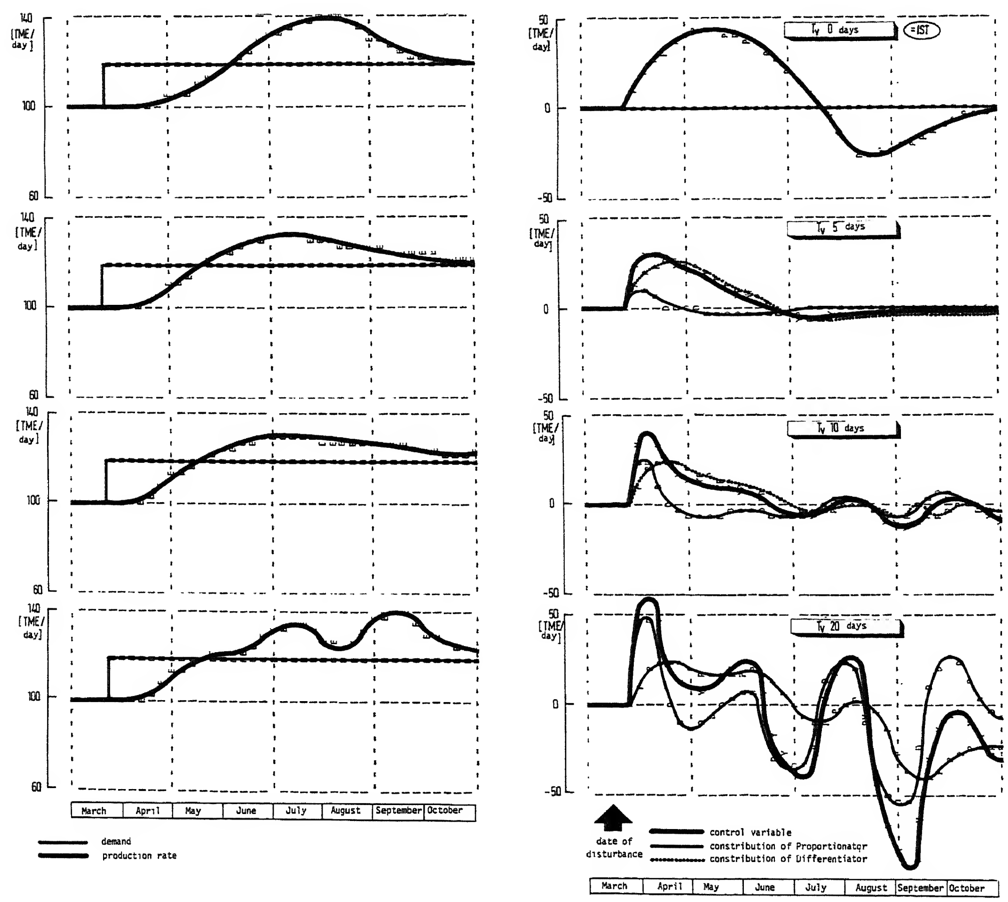

Figure 7: Impact of a PD-control characteristic (as opposed to a simple P-control) on system's behaviour after an unexpected demand jump of 10%.

4. BENEFITS TO THE COMPANY

The model experiments together with the interpretational work in the project team have identified three major areas of improvement to the manufacturing efficiency.

First, simulated market conditions show that reserves in all three inventory stages seem high enough to allow an average decrease of stocks by 15 to 20% without increasing the risk of stockouts significantly. The situation of reserves looks more comfortable at inventories for raw materials and for semi-finished goods than for finished goods.

Second, a shortening of the reaction time of production control (i.e. the "delay" in the terminology of System Dynamics) from now 20 to 15 days would lead to a noticable improvement of the dynamic behavior. For operational planning such an action would mean that observed gaps in inventories have to be eliminated faster. Similarly a speeding up of the planning rhythm and a faster implementation of plans would result in a better dynamic behavior. Here the model has helped to balance faster response to higher cost effectively.

Third, the model simulations have indicated that a further significant improvement of the company's overall flexibility is possible through a set of improved decision rules in production control. Traditionally the production control function has been using a simple order point technique with the difference between actual stock and should-stock being the order quantity. This is, in terms of control theory, a strictly proportional decision rule (P-characteristic). By using a slightly more sophisticated proportional/differential decision rule (PD-characteristic) the flexibility of manufacturing may be improved considerably. Figure 7 shows (from top to down) the effects of this change in production control upon the systems' reaction to a 10% increase in market demand.

These recommendations have been accepted by the company as feasible and promising and have been partly implemented already.

5. SUMMARY

In a joint project team a leading German manufacturer of consumer products and the Betriebswirtschaftliches Institut der Universität Stuttgart have developed and installed a System Dynamics model of the complex interactions of order entry, delivery rates, manufacturing rates and inventory levels. The model has helped to understand the logistical aspect of manufacturing efficiency better and to design and evaluate policies for an improved dynamic response behavior of the company to market disturbances.

USE OF GROUP TECHNOLOGY CONCEPTS

IN INTEGRATED PRODUCTION PLANNING

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INTRODUCTION

This study emphasizes the use of Group Technology concepts in the design of an integrated production planning and control system. In doing so, the manufacturing difficulties and the various complexities in the design and use of such a system in jobbing manufacture or small batch manufacture will be elaborated upon. The main complexities in jobbing manufacture stems from the variability in the volume and mix of the products and from the nature of demand. Jobbing manufacture is characterized by a complex work-flow structure and highly variable manufacturing times which complicate the production planning and control activities. High throughput times, extensive delays, high work in progress stocks, low utilization of labour and machinery, demanding supervision and control of production are the basic indicators related to the problems encountered in production planning and control activities in jobbing manufacture.

Regardless of the difficulties in jobbing manufacture, the demand for customized products with special requirements is growing. Groover (1980) states that the estimates for manufactured parts in lots of 50 or fewer will constitute 75% of the overall manufactured parts in the years to come. He also states that the present percent of parts in this category is estimated to be within the range of 25% to 35%. These figures reflect the fact that the jobbing manufacture will not only retain its present share but will make up the higher portion of the overall manufacturing activities. Hence the development of systematic procedures which will simplify and rationalize the production planning and control activities in an integrated fashion in jobbing manufacture need to be concentrated upon.

INTEGRATED PRODUCTION PLANNNING AND CONTROL SYSTEM

The basic elements of an integrated production planning and control system (IPPCS) are distinguished from one another by simply considering the time period involved in designing these elements. The long term planning activities consist of long term capacity planning and master production planning. The short term planning activities are referred to as detailed planning or scheduling activities. Successful production and control system needs to integrate these activities so that the transition from long term to short term plans is achieved by meeting the manufacturing targets set forth. To clearify the subject the elements of IPPCS need to be investigated in depth.

Long term capacity planning (LCTP) solely deals with the adjustment of resource levels which cannot be changed in short period of time. The inputs of LTCP are basically the demand forecast, market research, manufacturing and design attributes of parts and the current work load and stock levels. These information is used in calculating the required capacity in terms of labour and machine hours. However further information on the financial standing and the technological level of the firm need to be assessed to ascertain if the required production level can be obtained or not. The output of LTCP consists of the decisions related to the levels of workforce, machinery, stock levels and other resources.

Having ascertained the long term capacity level then comes the stage of planning the best way of using this capacity. The decisions given at his stage which is referred to as master production planning (MPP) consists of what to manufacture, how much to manufacture and when to manufacture so that the available capacity is utilized in the outmost manner or a specific objective function is either maximized or minimized to this end. The inputs of MPP are similar to those of the LTCP and the outputs of LTCP.

The immediate stage before the execution of manufacturing activities is the detailed production planning (DPP) stage. DPP consists of short term production planning and control activities such as assessing manufacturing attributes and priorities, sequencing, scheduling, dispatching, inspection, expediting of parts and evaluation of manufacturing performance. These activities are unified towards the achievement of production targets set by the master production plan.

As its name implies IPPCS is expected to set up the appro - priate links between these elements so that short and large term manufacturing activities are coordinated and executed to attain the overall manufacturing efficiency. More detailed treatment of the subject is given by Holstein (1960) and Eilon (1962). Within

the framework of IPPCS outlined in this section, the role of GT concepts in the preparation of long and short term manufacturing plans will be investigated in depth in the following sections.

GROUP TECHNOLOGY

To eliminate the aforementioned problems related to jobbing manufacture GT concepts have been used as a means of bringing the principles and advantages of higher volume flow production to small quantity production. GT is defined by NEDO(1975) as "the organization of production in self contained and self regulating groups or cells, each of which undertakes the complete manufacture of a family of parts having similar manufacturing characteristics". The review of related research by Opitz and Wiendahl (1971), Edwards and Keonigsberger (1973), Durie (1976) and Nişancı and Sury (1981) indicates that GT in manufacturing offers the potential of improved work flow, throughput times, work in progress stocks and machine utilizations. These potential improvements in using GT embrace a wide spectrum of manufacturing activities ranging from machine tool manufacture to light assembly work such as shoe manufacturing which are characterized by jobbing manufacture. Improvements obtained from the application of GT concepts especially in the form of multiple product families on multiple product manufacturing lines are also summarized by Willey and Dale (1977,1979). Furthermore Willey and Dale (1977) also report nonquantifiable improvements obtainable from using GT such as better control of manufacture, more flexibility in production programme, reduced absenteeism and paperwork, rationalization and standardization of planning,improved environment for solving engineering problems and improved management function.

GROUP TECHNOLOGY AND INTEGRATED PRODUCTION PLANNING AND CONTROL

Using the GT concepts a manufacturing system, a factory or a machine shop, is partitioned into smaller manufacturing subsystems named manufacturing cells. Even a further step can be taken to form multi-product lines from each one of these cells formed to manufacture the assigned product families as given by Nişancı and Gürlek (1981). These cells are formed by finding product families and the machine groups to manufacture these families. The families formed can be design or production families. To form the design families various coding schemes have been developed such as MICLASS, VUOSO, BRISCH, OPITZ etc. which consider similarities in design. The production families which include parts dissimilar in design but having one or more operations in common can be formed by using the techniques such as production flow analysis of

Burbidge (1971), similarity coefficients method of McAuley (1972) and Rank cluster algorithm of King (1980).

The partitioning of a manufacturing system into cells highly reduces the complex interaction between the machines or operation centres which is typical of jobbing manufacture. In other words the movements of parts are confined to limited number of machines. This in turn facilitates the preparation and execution of integrated production plans. At this point the role of GT in preparing the elements of an integrated production planning need to be investigated.

Group Technology and Long Term Capacity Planning

Long term capacity planning (LTCP) was stated to involve decisions on the level of resources which could not be changed when need arises. The basic relation to find the number of machines would be expressed in the following form;

$$M_j = \sum_{i=1}^{k} P_{ij} D_i / exa \qquad \text{for } j= 1,\ldots,k \text{ and where,}$$

M_j = Number of type j machines required,

P_{ij}= Processing time of product type i on machine j,

D_i = Demand for product i,

e = Machine utilization factor ($o<e<1$),

a = Available working time over a period of time.

As it is seen from the above relation the number of machine required depend on the machine utilization factor. This factor takes care of typical unexpected shop floor occurences which disrupt manufacturing. Furthermore the high competition among various parts for common machines also causes machines' idle times which need to be considered by this factor. Forming cells facilitates LTCP by providing the basis for more realistic capacity estimates and by simplifying the process of determining the real bottlenecks. The utilization ratios of machines in jobbing manufacture may take values from below 10% to over 90%. In general the overall system utilization is considered to be satisfactory if it is over 50% and the accepted average is about 40%. Thus having eliminated the work flow complexity in a typical jobbing manufacture, in which transfers of parts between any pair of machines is possible, via forming cells, the competition of entirely different parts on the same machines is avoided. Hence a more realistic basis exists to assign machine utilization factors and to determine under or over utilized machines for LTCP decisions if LTCP is done on cells basis.

Owing to the complexities inherent in jobbing manufacture, analysis on these types of systems have often been carried out by representing them as queueing networks. Also considering the stochasticity in jobbing manufacture, the behavior of these systems have been evaluated for specific capacity and input levels configurations by using simulation. In such situations the bottleneck machines can be determined but when a capacity increase on those machines are introduced some other machines tend to form bottlenecks. In other words, the capacity adjustments made in this fashion trigger a kind of a chain reaction in terms of bottlenecks. On the other hand input-output relation between the machines in a cell can be easily traced and corrective action to eliminate capacity imbalances can be taken more readily. Especially if the cells are transformed into multi-product lines, the bottleneck machines can be spotted by just viewing the in-progress stocks along the line.

Group Technology and Master Production Planning

In the preparation of a master production plan mathematical programming models have been used extensively. Using these models what to manufacture, how much to manufacture, and when to manufacture over a time period can be found by minimizing the overall manufacturing costs. However the manufacturing sequence of the parts and hence their interactions on machines basis cannot be represented in these models. On the other hand during the manufacturing, very frequently a decision need to be given what part is to be dispatched next. Therefore it is very common to have machines waiting for parts or vice versa eventhough the shop load level is calculated to be approximating the available capacity. Thus capacity constraints used in master production planning may not be representative of the real capacity. One way to get around this problem is to reduce available machine hours by 40%, as done in long term capacity planning, in formulating the master production plan capacity constraint. In spite of this over or under utilization cases can be faced during the short term production planning.

Naturally this problem stems from the variability of parts' routings and their manufacturing times. If cells are formed using GT then this variability can be reduced, and the master production plans prepared individually for each one of the cells can yield more realistic results. This improvement is attributed to the composition of the cells which are expected to reduce set-up times and work flow complexity by bringing together the parts requiring similar operations. This coupled with simplified and better control of manufacture assures minimum machine idle times in the cells. Furthermore the formation of cells permit the decomposition of mathematical programming models used in MPP by creating independent manufacturing units. This reduces the number of variables and constraints used in the models so that they can be managed more easily.

Group Technology and Detailed Production Planning

Detailed production planning (DPP) is the means of achieving the production targets set by the master production plan. Variability in parts routings and their processing times is the main source of difficulty in the preparation of DPP. The formation of cells results in similar parts being manufactured on specified set of machines and in increased repetition of operations. This enables the development of manufacturing methods and standard times which assist DPP. Having product families and machine groups formed,the sequencing and scheduling efforts can be significantly simplified as a result of dealing with smaller number of parts and machines. The parts in each cell need to be sequenced and scheduled depending on the requirements of the master production plans prepared for each cell. Moreover, since the master production plan specifies the quantities and types of parts to be manufactured the sequencing problem can be solved instead of dynamic scheduling. In the sequencing literature, optimizing algorithms up to "n" jobs "3" machines and reliable heuristics for "n" jobs "m" machines sequencing cases exist. Using these approaches the best sequence of parts can be found to minimize the criteria such as make-span.

In case probabilistic and continuous order arrivals exist then the sequencing work takes the form of dynamic scheduling which consists of selection of the best scheduling rules for the cells considered. In other words classical job-shop simulation study need to be performed for the cells individually. The factories manufacturing vast number and variety of parts have faced the problem of production control besides DPP. In fact the amount of control required is affected by the quality of DPP. The panacea has been found to be the use of on-line computers at the shop floor level to plan and control the manufacturing activities. However, the use of computers in this manner without rationalizing the manufacturing system but placing the burden of all these activities on the computer. Accepting that these activities are facilitated by the computer, it may well be the case that high speed and big capacity computers are used though not required.

In the light of the aforementioned points the group technology and integrated production planning and control system interface can be shown as in Figure 1.

GROUP TECHNOLOGY FACTORS AFFECTING INTEGRATED SYSTEM

The cells could be set up based on the families formed using either or low degree of subdivision. Families formed by high degree of subdivision involve the consideration of many product attributes and fine graduation over these attributes. High degree subdivision results in many but small sized families and the similarity between

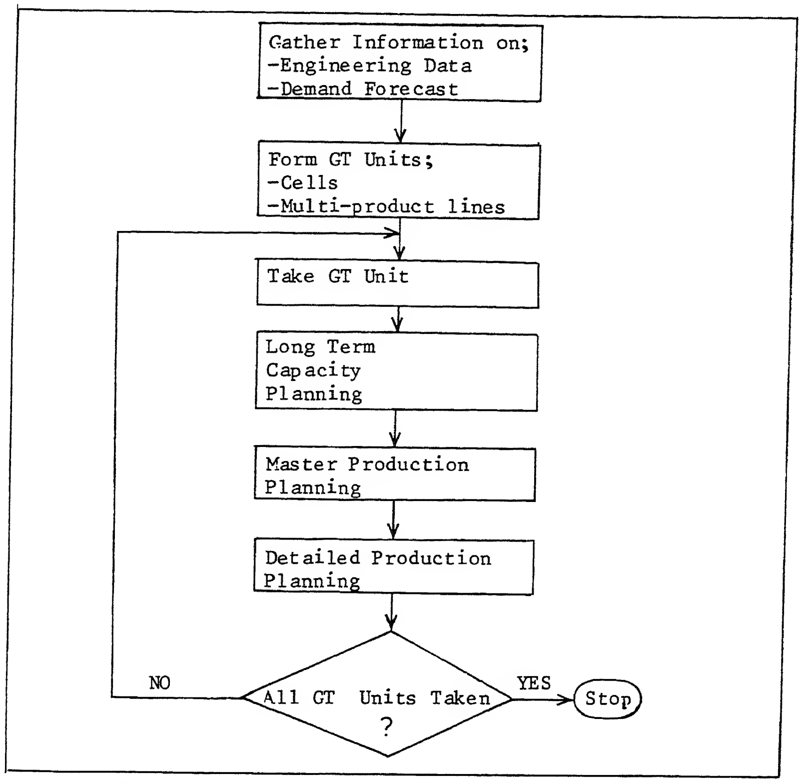

Fig. 1. GT integrated production planning and control interface

the family members is very high. This situation represents the ideal case for the development of an integrated production planning and control system due to having "n" independent cells. However the work load levels in such a situation may not be sufficient for a high utilization of machines. To a certain extent the use of flexible work force within the cells may increase the labour utilization. The other point to be considered is that such a cell design may result in poor flexibility which may not be able to adopt to changes in design or manufacturing requirements.

It is also possible to form families by considering few product attributes and using rough graduation which may result in low degree of subdivision. This results in few families consisting of higher

number of not very similar parts. Such an approach would lead to decreased number of machines required probably with higher utilization ratios. However the manufacturing cells formed using lower degree of subdivision would not be very far away from the original jobbing manufacture situation in terms of work-flow complexity. In such a dvision the machines would be shared by a high variety of parts which affects planning, control and supervision activities adversely. Other aspects of subdivision can be found in the work of Carrie (1977).

The interface of low and high degree of subdivisions in forming families with the integrated production planning and control activities and the related criteria is shown in Figure 2. Unfortunately there are no quantitative measures which can be used to determine whether the subdivision is of low or high degree. However considering the pros and cons of subdivision degrees the best compromise need to be found. The optimum level of compromise is quite difficult to find since many conflicting factors are involved. Simulation seems to be the appropriate technique which can be used to this end. The two extreme organizations of manufacturing shown as the pure job-shop and GT multi-product lines in Figure 2 indicate the starting and ending points respectively in using the GT concepts.

ROLE OF GROUP TECHNOLOGY IN FUTURE DEVELOPMENTS

Group technology data files help to assess the design and manufacturing characteristics of each part which enter the manufacturing system. Evaluation of design and manufacturing attributes of parts data by means of the GT classification system enables the integration of computer aided design (CAD) and computer aided manufacturing (CAM) technologies. Such an integration facilitates the use of computer aided process planning (CAPP) by which computer generated routings, operations and set-up sheets and time standards can be obtained. Thus a faster manufacturing response can be achieved by means of using the GT data base for design and manufacturing standardizations which facilitates the use of CAD,CAM and CAPP technologies. Furthermore, redundancies in parts design and manufacturing can be greatly eliminated by being able to recognize similar parts from the existing data.

GT concepts also play an important role in the design of flexible manufacturing systems (FMS) which are automated manufacturing systems. These systems are made up from a group of computer controlled machines linked together with auomated materials systems to completely process a group of family of parts. FMS are modernized types of conventional jobbing manufacture and they are capable of simultaneously processing multiple part types. Advanced and expensive technology is used in FMS and their application and

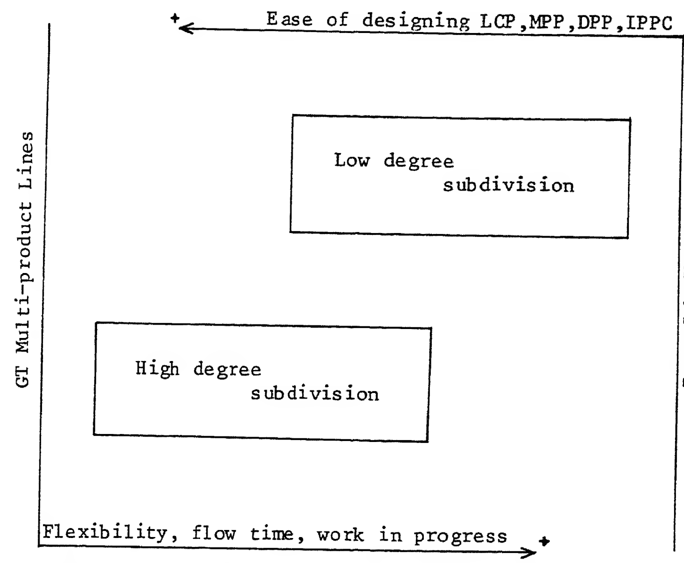

Fig. 2 Interaction between degrees of subdivision, planning activities and performance measures

scope is expected to increase in the very near future. Naturally for such systems new product designs need to be accepted with minimum cost and high productivity is a must. To assure these highly depends on the integration of GT in FMS so that appropriate families and cells are formed.

The growing technological advancement urges the necessity of using GT concepts in rationalizing manufacturing. The use of GT in combining these new technologies seems to be unavoidable. Also since expensive technologies used the role of integrated production planning and control for the best utilization of these resources is becoming more significant.

CONCLUDING REMARKS

After viewing various aspects on the use of GT concepts in designing an integrated production planning and control system, it is worthwhile to make the following concluding remarks on the core issues covered.

(a) Use of GT assists the rationalization of jobbing manufacture and eases the complexities encountered in such manufacturing systems.
(b) Long range capacity planning can be prepared more realistically for the GT cells in which a high interaction between numerous parts and various machines is eliminated.
(c) Master production plans can be reduced to manageable sizes if they are prepared on GT cells basis.
(d) Reducing the variability in the parts'routings by forming GT cells facilitates short term production planning. Hence the use of optimizing algorithms or successful heuristics becomes possible to solve the sequencing problems.
(e) Flexible integrated production planning and control modules can be developed to be used on each GT cell separately.
(f) Use of GT data base forms the basis for a transition to the use and integration of new manufacturing technologies such as CAD,CAM,CAPP, and FMS.
(g) Particularly the trend towards the use of new technologies and automated manufacturing systems enforces the preparation of integrated production planning and control systems for consistent manufacturing units which can be formed only by using GT since under utilization could not be afforded in such a high technology and costly systems

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A CLUSTER ALGORITHM FOR PROCESS LAYOUT

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The advent of CAD/CAM, the use of Flexible Manufacturing Systems, and the acceptance of the concept of The Automatic Factory has led to an increase in the need for mathematical or algorithmic approaches for control of manufacturing operations.

This paper discusses the use of such methods which can be applied to the application of computers for control of manufacturing.

In order to solve layout problems of this nature, and to establish a unified approach for product type layouts, a general production flow algorith can be used. There are three production flow stages suggested by Burbridge which require analysis in order to determine the most appropriate method of layout necessary for the manufacture of a range of products. These stages being: Factory flow, Group and Line analysis.

To reduce the variety and problems of applying separate analytical techniques to each of these stages of production a single algorithm which can be applied repeatedly in order to analyse the product range of a company is desirable.

The method of using this type of approach is to identify the overall aim of each analysis stage in the process, and then to carry out the analysis in two steps for each stage these are:

Division by incompatable processes and
Divisions into naturally existing cluster structures

The number of divisions which result from the first step is obtained from the number of different technologies employed within the manufacturing process (eg. machining, forming, assembly, etc.)

The number of divisions as defined in the second step is a function of the number of similar components produced, and similar assembly operations in the manufacturing process.

In order to fit the stages suggested by Burbridge into a single algorithm, each of these stages must be examined and related to a Product flow analysis based on the two principal divisions.

To analyse data of the size encountered in manufacturing problems matrix methods are generally used in such an analysis, the first step is to organize the data into strongly connected sub-groups having weak interactions between them. The techniques used to achieve this are termed clustering,data re-organization, block decomposition, production flow analysis, or numerical taxonomy.

The main objectives of these techniques are threefold,

1) To determine a method by which the array of coefficients appear in a clustered form, which reorders the rows and columns of the matrix array.

2) To interpret the clustering in such a manner as to be easily implemented in a manufacturing system.

3) To carry out this manipulation with minimum cost with respect to computation and implementation.

The Bond energy algorithm is used to identify naturally existing groups of coefficients in unordered arrays and to display their inter-relationships. This is accomplished by manipulation of the rows and columns of a data array so that the numerically larger array values are grouped together which is achieved by determining the Measure of Effectiveness. The measure of effectiveness of an array indicates how effective the manipulation has been in clustering these elements.

The assembly process, when defined as being finished components joined together to produce a product, occurs in the engineering, shoe and furniture-making industries.

The assembly process consists of a succession of positioning and fastening operations. Whereas the positioning operations are of importance in designing the assembly station, the grouping of re-occurring assembly operations for a given product range may lead to the design of specialized assembly machines, stations, or assembly lines, additionally, it could enable the collation of simple assembly tools and their power supplies to facilitate fastening methods.

The object attribute array used to find groups of machines can, when changing the interpretation of the rows and columns of the array, be used to determine families of assemblies. If the rows of the matrix are interpreted as fastening operations then clustering can be used to determine assembly stations, or assembly machines.

When an attribute array has been rearranged for the purpose of clustering, it is then a simple matrix manipulation which enables a product oriented manufacturing layout to be obtained.

The schematic plant layout developed by Carrie represents the result of the classification process of McAuley, finding groups of machines which can produce families of similar components, in the form of a minimal spanning tree. The minimal spanning tree joins each department or machine to the one that should be closest to it in order to minimize the material handling effort.

The principle of the spanning tree can be used to interpret the results of the matrix manipulations. Consider the matrix which relates machines and components:

		Components	
		1 2 3 4 5 6	
	1 (Milling)	0 1 0 1 1 0	
Machines	2 (Drilling)	1 0 1 0 0 1	$= [A_1]$
	3 (Turning)	0 1 0 1 1 0	
	4 (Flame Cutting)	0 0 1 0 0 1	

<u>Clustering</u>

		Components	
		3 6 1 4 2 5	
	4 (Flame Cutting)	1 1 0 0 0 0	
	2 (Drilling)	1 1 1 0 0 0	
Machines	3 (Turning)	0 0 0 1 1 1	$= [A_2]$
	1 (Milling)	0 0 0 1 1 1	

Multiplying the matrix $[A_1]$ by its transpose $[A_1]^T$ will result in the machine/machine matrix.

$$
\begin{array}{ccc}
 & & \text{Machines} \\
 & & 1\ 2\ 3\ 4 \\
\text{machines} & 1 & 3\ 0\ 3\ 0 \\
 & 2 & 0\ 3\ 0\ 2 \\
 & 3 & 3\ 0\ 3\ 0 \\
 & 4 & 0\ 2\ 0\ 2
\end{array}
$$

This matrix is a symmetrical matrix whose diagonal represents the row sums of the matrix $[A_1]$, and can be interpreted as the number of components visiting the machine. Similarly the diagonal could be interpreted to the number of components going to a processing department. The off- diagonal values indicate the number of reactions between any two rows and indicate interaction between machines and/or processes.

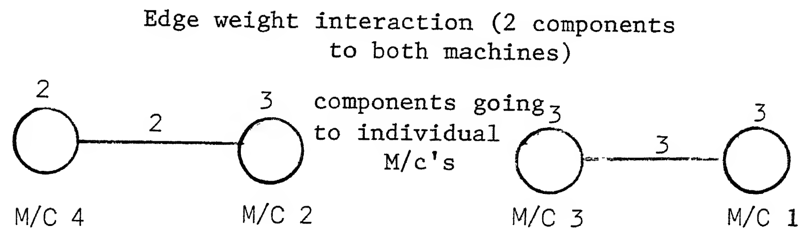
If this matrix $[A_1]$ $[A_1]^T$ had the matching algorithm applied to it or if the previous matrix had the clustering applied to it as in matrix $[A_2]$ then by multiplying $[A_2]$ by its transpose $[A_2][A_2]^T$ would produce the clustering matrix.

$$
\begin{array}{ccc}
 & & \text{Machines} \\
[A_2][A_2]^T = & & 4\ 2\ 3\ 1 \\
\text{machines} & 4 & 2\ 2\ 0\ 0 \\
 & 2 & 2\ 3\ 0\ 0 \\
 & 3 & 0\ 0\ 3\ 3 \\
 & 1 & 0\ 0\ 3\ 3
\end{array}
$$

In this example two distinct clusters are produced, the zeros in the matrix indicating there is no interaction between the groupings.

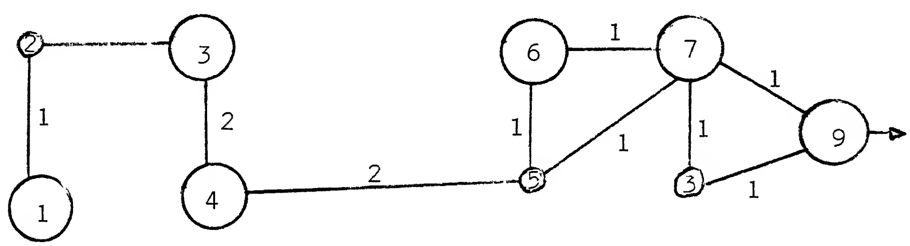
Using graph theory to interpret the matrix $[A_2][A_2]^T$ then it can be stated that a tree layout is a weighted graph composed of a set of points (nodes) and a set of node pairs (edges) with a number (weight) assigned to each edge. A sequence of edges joining two nodes being termed a path, a closed path being termed a circuit, a graph without any circuits is termed a tree. A spanning tree being a tree which contains all the nodes appertaining to that tree, with a weight being the sum of the weights of its constituent edges.

Thus the interpretation of $[A_2][A_2]^T$ can be obtained by using the diagonal entries as the nodes (departments, machines etc.), and the off-diagonal entries as the edges which represent the interaction of the nodes with each other. From this interpretation, the layout can be interpreted as:



The graph shows two parts, where each part is a separate spanning tree. The weight of each subgraph is the weight of one edge only, as there are only two machines interacting.

If the operating characteristics of the machines are known, and in addition, the production requirements specified, it will be possible to determine the number of machines, floor area, etc. which would be required. This could be incorporated in the tree layout.



A Typical Capacity Tree Layout

(nodes 1, 3, 4, 6, 7, 9 indicate 2 machines whilst nodes 2, 5, 8 represent one machine).

As an example of this approach, consider the manufacture of seven components on four machines:

To obtain the Clustering structure, represent the component machine relationship in an object attribute array.

$$
\begin{array}{ll}
 & \text{Components} \\
 & \begin{array}{ccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 \end{array} \\
\text{Machines} \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \end{array} & \begin{array}{ccccccc} 1 & 1 & 0 & 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & & 1 & 0 & 1 & 1 \end{array}
\end{array}
= [A_1]
$$

Apply the cluster algorithm to obtain an ordered array

$$
\begin{array}{ll}
 & \text{Components} \\
 & \begin{array}{ccccccc} 3 & 6 & 1 & 7 & 2 & 4 & 5 \end{array} \\
\text{Machines} \begin{array}{c} 3 \\ 1 \\ 4 \\ 2 \end{array} & \begin{array}{ccccccc} 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 \end{array}
\end{array}
= [A_2]
$$

To establish the proximity between clusters then multiply $[A_2][A_2]^T$ to obtain

$$
\begin{array}{ll}
 & \text{Machines} \\
 & \begin{array}{cccc} 3 & 1 & 4 & 2 \end{array} \\
\text{Machines} \begin{array}{c} 3 \\ 1 \\ 4 \\ 2 \end{array} & \begin{array}{cccc} 3 & 3 & 0 & 0 \\ 3 & 5 & 2 & 1 \\ 0 & 2 & 4 & 3 \\ 0 & 1 & 3 & 3 \end{array}
\end{array}
$$

Interpreting the result of $[A_2][A_2]^T$:

There are two links between the two clusters (3, 1, 4, 2)

1) the interaction between machine 1 and 4 which is 2

2) the interaction between machine 1 and 2 which is 1

The heaviest interaction between machines indicates they should have the interacting machines closest to each other.

The cluster tree can be drawn

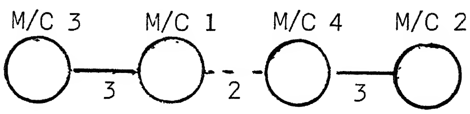


Fig. 1

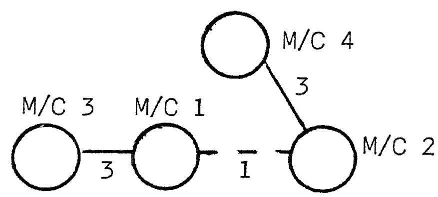


Fig. 2

There are two alternative links which could be used as shown in dotted lines; however, Fig. 1 would be preferable as it locates the machines with the heaviest interaction closest to each other.

The problem in using this method is to obtain an efficient clustering algorithm for data reorganization. Techniques used to organize data into groups are given in the literature as clustering, data reorganization, block composition, production flow analysis and numerical taxonomy. These techniques have a common objective.

Firstly, to determine a method for reordering the rows and columns for the matrix array to obtain the array coefficients in a clustered form. Secondly, to establish criteria which will enable the clustering to be interpreted in a meaningful way.

An algorithm, the matching algorithm, has been developed to achieve these criteria. To illustrate this algorithm, consider the Bond Energy algorithm developed to identify naturally existing groups of coefficients in unordered data arrays, and display their inter-relationships. This is accomplished by manipulating the rows and columns of a data array in such a manner that the numerically larger arrays are grouped together. A measure of effectiveness is then developed, based on the bond strengths in the array. The shortest spanning path algorithm interprets the sequence of rows (or columns) of a data array as a path of graph G. The clustering is achieved by bringing together elements of the array, using the concept of the shortest spanning path, for the formation of clusters.

The matching algorithm is based on the fact that the formation of clusters from an unorganized data array can be based on the number of matchings of the zero and non zero entries between two parallel lines of the array (rows and columns).

The matching concept can be defined as whenever two rows (or columns) of an unordered array are compared and their entries are identical a match exists; otherwise a mismatch is obtained.

The procedure for this algorithm can be stated as:

4.3.2 The Steps of the Matching Algorithm

Step 1: From an m x n matrix array A compute the m x m array $A*A^T$ (A^T*A forms the n x n array for column ordering). The * designates a matching count between the rows of A and columns of A^T; $A*A^T$ is a square symmetric matrix of size m x m where the (i,j)th entry represents the number of matchings between the rows i & j of the matrix A.

Step 2: Select one of the m rows of $A*A^T$ arbitrarily; set i = 1.

Step 3: Select j = i + 1.

Step 4: Try placing the jth row in each of the (i + 1) positions.

Compute the sum $\Phi = \sum_{i=1}^{m-1} b_{i,i+1}$, where $\{b_{i,j}\} = B = A*A^T$ for each case and retain the maximum and the corresponding location. Let the maximum be Φ for the position r_j among (i + 1) positions (the computer implementation calculates only the change in Φ).

Step 5: j = j + 1 and repeat step 4 until j = m. The corresponding Maximums of Φ occur at $r_{i+1} \ldots r_m$.

Step 6: Place the row k ($i + 1 \leq k \leq m$) which caused the most change in steps 4 & 5, in its corresponding location r_k, i.e. maximum Φ value is obtained when the kth row is placed in the position r_k.

Step 7: i = i + 1, repeat steps 3 through 7 until i = m. Repeat the above steps for the columns.

4.3.3 An Illustration of the Matching Algorithm

The example of matrix A Fig. 3 is used to illustrate the algorithm.

$$A = \begin{array}{c|ccccccc} & a & b & c & d & e & f & g \\ \hline W & 1 & 1 & 0 & 1 & 1 & 0 & 1 \\ X & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ Y & 0 & 1 & 0 & 1 & 1 & 0 & 0 \\ Z & 1 & 0 & 1 & 0 & 0 & 1 & 1 \end{array}$$

Fig. 3

$$A*A^T = \begin{array}{c|cccc} & W & X & Y & Z \\ \hline W & 5 & 1 & 3 & 2 \\ X & 1 & 3 & 0 & 3 \\ Y & 3 & 0 & 3 & 0 \\ Z & 2 & 3 & 0 & 4 \end{array}$$

(only matchings of '1' are counted)

Fig. 4

The above matrices represent the initial steps of data preparation.

The result of a typical iteration of Step 4 is shown in Fig. 5.

$$A*A^T = \begin{array}{c|cccc} & Y & W & X & Z \\ \hline Y & 3 & 3 & 0 & 0 \\ W & 3 & 5 & 1 & 2 \\ X & 0 & 1 & 3 & 3 \\ Z & 2 & 3 & 0 & 4 \end{array}$$

$$\Phi = \sum_{i=1}^{3} b_{i,i+1} = 7$$

Fig. 5

$$A*A^T = \begin{array}{c|cccc} & W & Y & X & Z \\ \hline W & 5 & 3 & 1 & 2 \\ Y & 3 & 3 & 0 & 0 \\ X & 1 & 0 & 3 & 3 \\ Z & 2 & 0 & 3 & 4 \end{array}$$

$$\Phi = \sum_{i=1}^{3} bi,i+1 = 6$$

Fig. 6

Row W was selected in step 3 and row Y in step 3 of the algorithm. Step 4 determines in which of the two possible positions row Y contributes the most matchings. (Fig. 5 $\Phi = 7$.)

The final re-ordering given by the algorithm defines the row order as Y, W, Z, X.

$$A*A^T = \begin{array}{c|cccc} & Y & W & Z & X \\ Y & 3 & 3 & 0 & 0 \\ W & 3 & 5 & 2 & 1 \\ Z & 0 & 2 & 4 & 1 \\ X & 0 & 1 & 3 & 3 \end{array} \qquad \Phi_{max} = \sum_{i=1}^{3} b_{i,i+1} = 8$$

Fig. 7

A similar procedure for the columns results in the column order f, c, a, g, e, d, b. Hence, rearranging the original matrix A will give the clusters:

$$A = \begin{array}{c|ccccccc} & f & c & a & g & e & d & b \\ Y & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ W & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ Z & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ X & 1 & 1 & 1 & 0 & 0 & 0 & 0 \end{array}$$

The shortest spanning path algorithm has the following interpretation in terms of the matching algorithm. In the case of the shortest spanning path the mismatch is counted instead of the match. The entries of matrix $\{b_{i,j}\} = B$ are obtained from

$$b_{i,j} = \sum_{k=1}^{n} a_{i,k} - a_{j,k}$$

where $a_{i,k}$ and $a_{j,k}$ are the elements of matrix A and minimize o:

$$o = \sum_{i=1}^{m-1} b_{i,i=1}$$

For example, in the case of data reorganization with 0 and 1 entries $A*\bar{A}^T$ gives this distance when both 0-matchings and 1-matchings are counted; $\bar{A}$ is obtained from A, by replacing zeros by ones and ones by zeros, thus:

$$\bar{A}^T = \begin{array}{c|ccccccc} & a & b & c & d & e & f & g \\ W & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ X & 0 & 1 & 0 & 1 & 1 & 0 & 1 \\ Y & 1 & 0 & 1 & 0 & 0 & 1 & 1 \\ Z & 0 & 1 & 0 & 1 & 1 & 0 & 0 \end{array}$$

From which:

$$A*\bar{A}^T = \begin{array}{c|cccc} & W & X & Y & Z \\ \hline W & 0 & 2 & 0 & 2 \\ X & & 0 & 3 & 1 \\ Y & & & 0 & 4 \\ Z & & & & 0 \end{array} \qquad A*\bar{A}^T = \begin{array}{c|cccc} & W & X & Y & Z \\ \hline W & 0 & 5 & 2 & 4 \\ X & & 0 & 6 & 1 \\ Y & & & 0 & 7 \\ Z & & & & 0 \end{array}$$

(only matchings of '1' are counted) (matchings of '1' and '0' are counted)

$$\Phi = \sum_{i=1}^{3} b_{i,i+1} = 9 \qquad \Phi = \sum_{i=1}^{3} b_{i,i+1} = 18$$

$$A*\bar{A}^T = \begin{array}{c|cccc} & Y & W & Z & X \\ \hline Y & 0 & 0 & 4 & 3 \\ W & & 0 & 2 & 2 \\ Z & & & 0 & 1 \\ X & & & & 0 \end{array} \qquad A*\bar{A}^T = \begin{array}{c|cccc} & Y & W & Z & X \\ \hline Y & 0 & 2 & 7 & 6 \\ W & & 0 & 4 & 5 \\ Z & & & 0 & 1 \\ X & & & & 0 \end{array}$$

$$\Phi_{min} = \sum_{i=1}^{3} b_{i,i+1} = 3 \qquad \Phi_{min} = \sum_{i=1}^{3} b_{i,i+1} = 7$$

4.3.5 Algorithm

The incremental changes for different arrangements in o are computed and the maximum of these changes is recorded. The change is computed in o as

$$\Phi = b_{j,k} + b_{j,k+1} - b_{k,k+1},$$

where the jth row is to be placed between rows k and $k + 1$.

A further computational saving is the calculation of $A*A^T$ which has to be carried out only once, as compared with other algorithms which require the calculation of interacting rows and columns at each iterative step.

The principle advantage of the matching algorithm is that when a row is rearranged, the change in the number of matchings need not be recomputed for each possible arrangement, instead only the change in Φ is evaluated which constitutes a considerable advantage as Production Flow Analysis generally involves the reordering of very large matrices.

The reduced compuational efforts can be illustrated by considering a matrix A of size m x n, then the number of operations necessary for the McCormick, Slagle and the matching algorithm compare as follows:

McCormick:

$$C_{McC} = \sum_{i=2}^{m} i(2n)\ (m - i + 1)$$

When a row is placed in i positions in McCormick's algorithm, 2n comparisons have to be made per position. This is repeated for all the remaining rows (m - i + 1) times for any given stage. Thus for one stage the total effort is

$$[i(2n)](m - i + 1)$$

for i = 2, 3, ..., m stages

Slagle:

$$C_{S1} = \sum_{i=2}^{m} i(2n)$$

Since in Slagle's algorithm, unlike in McCormick's, all the remaining rows (m - i + 1) are not checked at any stage, this factor does not appear.

Matching Algorithm:

$$C_{Match} = \sum_{i=2}^{m} 3i(m - i + 1)$$

Since only three comparisons can be made at any stage, for all i positions that an unorganized row can be placed in, the total effort at each stage is 3i. There are (m - i + 1) unorganized rows, which is repeated for i = 2, 3, ..., m.

From the above it can be seen that

$$C_{Match} << C_{S1} << C_{McC}$$

as

$$C_{Match} = 3 \sum_{i=2}^{m} i(m - i + 1)$$

$$C_{S1} = 2n \sum_{i=2}^{m} i$$

$$C_{S1} = 2n \sum_{i=2}^{m} i$$

$$C_{McC} = 2n \sum_{i=2}^{m} i + 2n \sum_{i=2}^{m} i(m - i)$$

Note that $m \geq i$, therefore $2n \sum_{i=2}^{m} i(m - i) \geq 0$ is positive.

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MATHEMATICAL DESIGN TOOLS FOR INTEGRATED PRODUCTION SYSTEMS

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INTRODUCTION

Long before the operating policies of a manufacturing system are considered, many design decisions are made which affect the ultimate ability of production managers to control the performance of the system. Although some of the more advanced companies employ simulation methods to "fine tune" their system designs, few make use of any formal methodology at all in the critical early stages. Fundamental design issues, such as how large the system will be or the selection of processing and material handling equipment, are usually dealt with by arbitrary choice or back-of-the-envelope calculations. It is ironic that the most important design decisions -- those having the greatest long-term impact on system productivity -- are handled in the least careful manner.

Most people assume that there is no alternative, that a system must be specified in considerable detail before it is possible to assess its performance. Since the number of alternatives is literally infinite, and one has to start somewhere, certain design parameters must they believe be chosen arbitrarily in order to reduce the scope of the exploration to a reasonable range. This belief is mistaken. It is possible to apply analytical performance evaluation methods even in the very early stages of design to assist in these fundamental decisions. This report discusses the nature of the system design problem, outlines some available mathematical tools, provides a brief example taken from an actual case, and finally mentions a few of the open research issues in this area.

My central focus is on machined parts which are produced in

small to medium batches. I am not directly concerned with, nor have I any special expertise for, electronic assemblies, plastics, glass, or other non-metallic products. The special purpose automation associated with mass production is also an area in itself which is not addressed here. The methods I discuss may be applicable in some of these circumstances, but they have not been thoroughly tested there. My efforts have been directed at that production sector which I consider to be in greatest need of scientific assistance.

One must realize that most manufacturing is not highly automated. The assembly lines and mass production facilities associated with high volume and process industries account for relatively little of the dollar value of manufactured goods. In fact, as much as three quarters of the goods, as measured in dollar volume, are produced in small batches[1]. Because the facilities that produce these small batches must continually adjust to new requirements, fixed automation does not make economic sense. Consequently, most such facilities are operated as job shops, with general purpose machines and many human operators. As a general indication of the magnitude of human effort involved, one 1979 survey estimated the cost of direct labor and direct labor overhead associated with general purpose metal cutting machine tools (such as mills, drills, and lathes) in the U.S. as $115 billion dollars per year[2]. Adding the cost of raw materials, amortization of capital costs and overhead, and extending the figures beyond metal cutting, one begins to realize that batch manufacturing accounts for a very substantial portion of the economy.

Just how inefficient are these factories today? It is common knowledge in the metalworking industry that even the most modern and expensive NC machine tools are typically utilized only thirty to forty percent of their capacity[3]. Another often quoted statistic points out that, of the total time that a machined part spends in the shop, 95% is spent waiting or traveling, 3% being positioned or fixtured, and only 2% being machined[4]. It is clear that there is much room for improvement. Moreover, when you combine these performance indicators with the dollar figures mentioned earlier, you can get an inkling of the magnitude of the waste.

THE NATURE OF THE PROBLEM

Here we are concerned with a design problem. As every engineer knows, design problems by their very nature involve more synthesis than analysis. Yet if you compare the design methodology of, say, circuit boards, to that of manufacturing systems you see an enormous discrepancy in the sophistication of tools. Certainly both require a good deal of human imagination, but the electronic engineer has a host of physical laws, mathematical models, established conventions and symbols, and computerized circuit analysis packages to assist him. Generally, manufacturing systems designers rely almost solely upon their experience and common sense. The science of production,

if it is fair to even use such a term, is still very primitive.

Admittedly, real life manufacturing systems are so complex that they appear to defy analysis. There are staggering quantities of data to deal with, myriads of exceptional disturbances to take into account, notoriously unpredictable human behavior to contend with, and so forth. On the other hand, any system which is not well understood appears to be complex. For all we know, there are undiscovered principles which, once known, will bring order to this chaos. Any of the classical areas of science can serve as examples in expressing this hope.

In searching for mathematical models to describe the behavior of manufacturing systems, one must adopt an appropriate global strategy. Some of the more attractive approaches (from the standpoint of mathematical tractability) simply do not capture the essential elements. For example, one might attempt to use a linear model, because the mathematics is so well developed and powerful. However, the most important behavior phenomena seem to occur precisely because of non-linearities. Similarly, one might be tempted to decompose a system into smaller components, but to do so would lose the effect of the interdependencies which play a large role in the system behavior.

There are some other factors which make our task difficult. In batch manufacturing, the discreteness of individual workpieces is normally significant. Thus the powerful methods of continuous analysis (differential and integral calculus) are of limited usefulness. Whereas in many fields of science and engineering, a statistical mechanics point of view -- that is, dealing with average behavior of large populations of particles -- tells you what you really want to know, the issues of concern in manufacturing systems usually force a particle-level viewpoint.

Moreover, one cannot often get away with assuming homogeneous populations. That is, individual parts will typically differ in processing times, routes, tool and fixture requirements, and so forth. These variations may be truly random (e.g., as when a machining time depends upon characteristics of the material which cannot be measured in advance), or they may be entirely predictable (e.g., as when the difference between machining times is due solely to the fact that different part types are involved). In either case, the variations give rise to populations of descriptive information, rather than singular values. This aspect, in turn tends to suggest stochastic, or probabalistic models, rather than deterministic ones. (Note that it is variability, not necessarily uncertainty, in the descriptive information that governs this choice).

Another characteristic of the real world problems that poses

difficulties is their dynamic nature. For many decisions, steady state performance measures may be sufficient, but the models that produce them must somehow account for the influences of dynamic behavior upon them. Many issues force attention to transient behavior.

Problems which are discrete, stochastic, and dynamic are perhaps the most difficult to handle, either mathematically or in practice. For many people, the difficulties appear so imposing that they give up immediately on finding rigorous methods for dealing with such problems. They resort to trial and error approaches, intuition, or unverified heuristics. Of course, these are the very methods we wish to replace. Considering the obstacles, it is perhaps not surprising that so few scientifically sound results have been produced to date.

A MATHEMATICAL MODEL, CAN-Q

Of course, there are many different approaches to obtaining useful analytical models. The one which is described here represents the workflow through a manufacturing system as a queueing process. It will be obvious that the model is highly aggregated, and is therefore unsuited to answering many detailed questions of design. It does, however, fulfill the special requirements of system designers in the critical early phases when many basic decisions are made. It is quick and easy to use, requires little data, and provides a wide range of performance measures with acceptable accuracy.

The time that an individual workpiece spends in a manufacturing system can be considered to consist of processing time, travel time, and delay time. The processing and travel times are inevitable, but the delay time is a consequence of the congestion that occurs as workpieces compete for resources. The facilities of the system that do active work, including the transport system, are considered stations. Let M represent the number of stations, with the material handling system, by convention, listed last. The others will be machines, load/unload stations, inspection stations, and so forth. Each station (which may have multiple servers) is assumed to have an unlimited queue to hold workpieces awaiting service.

The number of workpieces in the system is treated as a constant, denoted N. There are no arrivals or departures; instead, we imagine that a completed workpiece is immediately replaced by a raw casting.

With appropriate assumptions about the nature of workpiece routing, processing and travel time distributions, and queue disciplines, this view of a manufacturing system gives rise to a closed queueing network of the "Jackson" type. This class of queueing

networks has undergone many developments in the past few years, providing new theoretical results. In addition, the same class has been used with considerable success in modeling computer systems. Although there are important differences, manufacturing systems are in many ways analogous to computer systems.

Since the theory is well established and the technical details of the model have appeared before[5], only a brief overview of the mathematics will be provided here.

Under the usual assumptions, a sufficient description of the state of the queueing network is given by the state vector

$$\underset{\sim}{x} = (x_1, x_2, --- x_M)$$

where x_i represents the number of workpieces at station i, including both those in service and those waiting. The entire state space for the stochastic process is given by

$$S = \{\underset{\sim}{x} \mid x_i \geq 0, \forall i \; ; \sum_{i=1}^{M} = N\}$$

The required assumptions about the forms of distributions of random variables depends upon the queue discipline. Although not strictly necessary, it is easiest to follow the development if one assumes that all random variables are negative exponentially distributed, in which case the entire process is simply a multi-dimensional Markov process.

Let p(x) denote the steady-state, or equilibrium, probability of the process being in state x. The equations for p(x), though tedious to write, are straightforward linear equations when the process is Markovian. It has been shown that the solution is of the form

$$p(\underset{\sim}{x}) = \frac{1}{G(M,N)} \prod_{i=1} f_i(x_i)$$

where each function $f_i(\cdot)$ in the product depends only on station i (the particular form of the function depending on number of servers, queue discipline, and so forth), and G(M,N) is a normalizing constant having a value which assures that the probabilities of all states will sum to one.

The only difficulty in actually obtaining a numerical value for p(x) is in evaluating G(M,N). Although a typical real world system might possess billions or trillions of states, the evaluation of G(M,N) fortunately does not require summing over unnormalized solutions for each possible state. A recursive technique generates

G(M,N) by regarding M and N as variables. Starting from M=N=1, a difference equation relates each subsequent G(M,N) to previously generated values. Hence, the evaluation amounts to filling in the entries of an M x N matrix, the last entry of which is the desired normalizing constant.

Moreover, it turns out that all of the important steady-state performance measures for the system, such as production rate, mean flow time, utilizations, and mean queue lengths, can be computed directly from the entries of this matrix. For example, the production rate of the system is given by [G(M,N-1)/G(M,N)] times the mean transport time divided by the mean number of operations per completed workpiece. Thus the computation of such qualtities has been made not only feasible but easy.

A computer program called CAN-Q, for Computer Analysis of Networks of Queues, implements the model in a convenient form. The mathematical theory used to derive the algorithms is transparent to the user, so that he may give full attention to the manufacturing problem at hand. The program will support analysis at several levels of detail, but in no case does it require very much data. The configuration of the system modeled is arbitrary, travel times between work stations are treated, and an arbitrary product mix is permitted. Machine failures, part batching, and operator efficiencies can all be accounted for if necessary. Both input and output are designed to be natural and familiar to industrial users.

The program runs in negligible time on a large computer, and is compact enough to run on a micro. In fact, one version of the program (which sacrifices some useful features but does perform the difficult calculations) has been implemented on a pocket programmable calculator. Perhaps the most surprising characteristic of the model is its accuracy. Despite the aggregated treatment of many details, CAN-Q has been found to provide results which vary by only a few per cent from simulations requiring 100 times as much data.

The CAN-Q program and user's guide[6] have been supplied on request to about 400 companies, some of which have adopted it as a standard planning tool. It is also being used in research projects at several universities. The capabilities of the model, user-oriented features, and documentation are under continued development at Purdue. For some further background and applications, see references 7, 8, and 9.

AN EXAMPLE

The following design case is taken from an actual situation with which the author was involved. The treatment is abbreviated, of course, and the data is altered somewhat to protect proprietary

information. However, enough information is given to serve the purpose of demonstrating the basic methodology.

The first step in the system design process is to identify the essential components - the basic processing resources without which the production could not occur. The number of each and their spatial arrangement is not yet at issue; it is only necessary to identify them. In this case, a brief study was made of parts which were similar to the ones which the new system is to produce (the actual parts were not yet designed). Five groups of parts were defined. Within each group the parts were relatively homogeneous with respect to size, complexity, and processing requirements. Of course, the parts were visually and functionally dissimilar. Between groups, there were significant variations even in processing requirements. It was determined that six different types of stations would be needed: fixturing, billet preparation, machining, deburring, manual inspection, and automated inspection. Material handling is also necessary, of course, but the needs for this are driven by the processing requirements and system configuration.

The next step is to size and configure the system so that enough copies of each component type are provided to achieve the desired production capacity and that they are supplied in proportion to the needs. The problem was complicated somewhat by uncertainty about the product mix and future production capacity to provide for. Because of the long lead times involved in constructing a system, this situation is really not atypical. The objective is to find a system design which meets the best estimate of future requirements, but is not very sensitive to variations in the unknown parameters.

It is quite easy to do this using CAN-Q. The mean processing times for each product group were taken as representative of future times of similar products. That is, a part belonging to a certain group was assumed to require a time for fixturing, machining, etc. equal to the mean value for the group. Since CAN-Q treats this value as the mean of a random variable, rather than a fixed constant, variations are accounted for automatically. Then the five groups were mixed in accordance with the best estimate of the proportions required, e.g. 20% type 1, 15% type 2, etc.. (Later these values were varied to check the sensitivity of results to errors in the assumed values.)

The sizing of the system was accomplished as follows. Starting with the smallest possible system that could perform the functions, i.e. six stations plus a transport mechanism, CAN-Q was run to assess the performance of that possible configuration. One of the pieces of information derived from that run is the system bottleneck, the most heavily utilized station. If one more unit of any processing type were to be added, the greatest production

increase would occur by incrementing the number of units of the bottleneck type. (Though it should be pointed out that, since costs are not considered here, such an improvement is not necessarily the most cost-effective improvement.) Hence the number of servers at the bottleneck station is incremented by one, and the program is run again, the new bottleneck is identified, and so on. As the capacity of different stations increases, the bottleneck shifts. The productive capacity of the system as a whole increases as additional units are added, but not smoothly. Sometimes relieving a bottleneck allows the rate to jump considerably; other times only a slight increase occurs before the next bottleneck constrains the flow. Figure 1 illustrates the relationship between system size and production rate.

If an absolute requirement in terms of minimum production rate were known, this graph could be used to identify the minimum sized system capable of reaching that level. However, the issue is not usually so clear, nor was it in this case. Moreover, the various system sizes are not equal in their relative efficiencies. Figure 2 graphs the overall mean utilization of processing units as a function of the system size. The smaller systems exhibit fairly poor usage of the resources, as a consequence of a mismatch or imbalance between the relative work loads and the relative number of units. For example, if the load on machining is one-and-a-half times the load on deburring, then there ought to be about one-and-a-half times as many machines as there are deburring stations. Since they can only be added in integer amounts, a system must reach a certain size before these ratios can be satisfied. Maximum utilization occurs, in this case, for a system having a total of twenty units (apportioned appropriately among the six types, of course). However, larger systems could be built with little loss of efficiency.

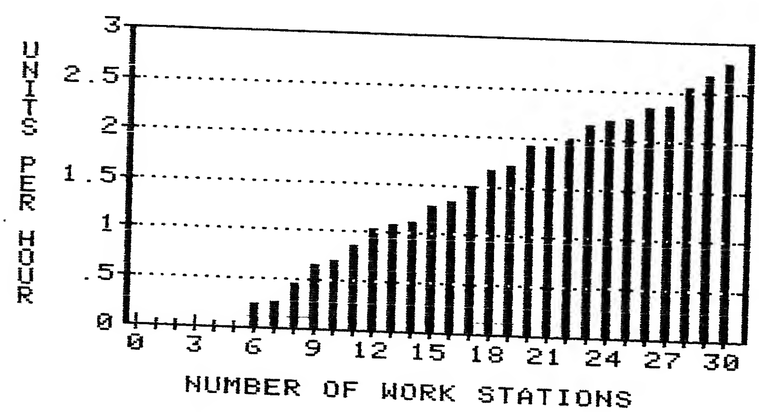

FIG. 1 PRODUCTION RATE

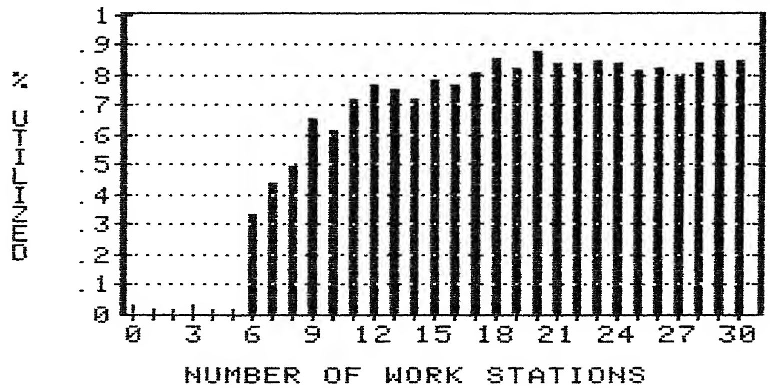

FIG. 2. SYSTEM UTILIZATION

At some point, diseconomies of scale become apparent. When the system gets very large, the material handling becomes a serious problem. There is a limit to the speed at which you can move the parts, imposed by both safety and physical constraints. Up to a point, you can compensate by adding more transporter units, but eventually the traffic problems limit this approach also. Although figure 2 does not display this effect prominently, it has shown up clearly in other examples.

Figures 3 and 4 illustrate the behavior of the average in-process inventory and the mean flow time (total of processing, transport, and delay) as functions of the system size. Both of these are irregular in their behavior, reflecting the changing conditions.

For any given configuration, it is possible to explore additional trade-offs among production rate, in-process inventory, and flow time. Figures 5 and 6 show the general nature of the relationships. The production rate varies as a function of the in-process inventory between zero and a maximum rate which is essentially determined by the bottleneck. Simultaneously, the flow time starts at a minimum which occurs when there is no congestion (inventory = 1) and increases without limit. One can elect to operate at any particular intensity level, but once one of these three values is set, and assuming all other factors remain constant, the other two are determined. CAN-Q produces the information in a single run to explore the alternatives. The method of selection used in the analysis leading to figures 1-4 was to set the production rate 95% of the maximum limit. Of course, these limits change from run to run.

The information shown was produced in about fifteen minutes at a terminal. Subsequent analysis investigated the sensitivity of results to the product mix, variations in material handling, includ-

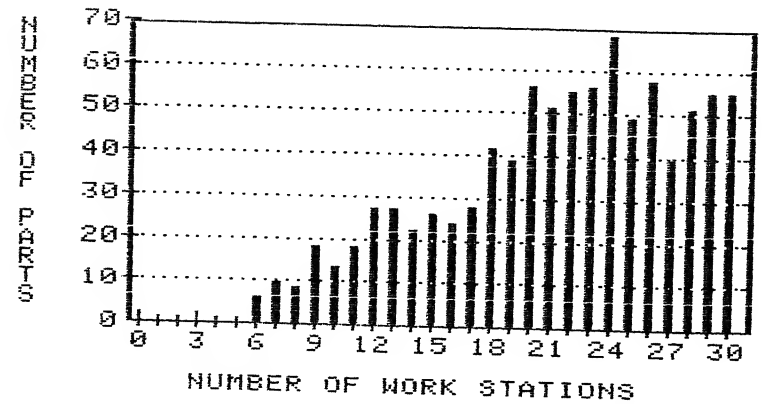

FIG. 3. IN-PROCESS INVENTORY

ing number and speed of transporters, changes in technology which would affect processing times, and several options for batching jobs. The original data was also revised several times, which necessitated a repetition of the entire analysis. As mentioned earlier, the design environment is fraught with uncertainty. The ability to explore many variations interactively and to experiment with innovative concepts at a very low penalty in terms of either cost or time greatly enhances the entire design process.

Like any model, CAN-Q has limitations which restrict its usefulness for some kinds of analysis. It is only a descriptive model; that is, it predicts the consequences of a fixed set of circumstances without attempting to optimize anything. It produces only long-term mean values for the performance measures, which are ap-

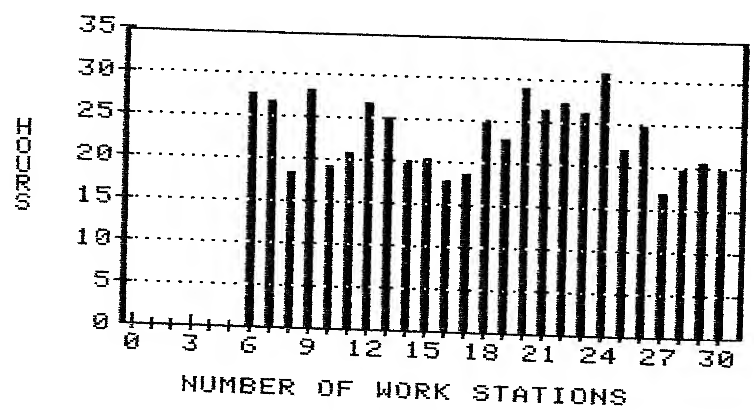

FIG. 4. TOTAL TIME IN SYSTEM

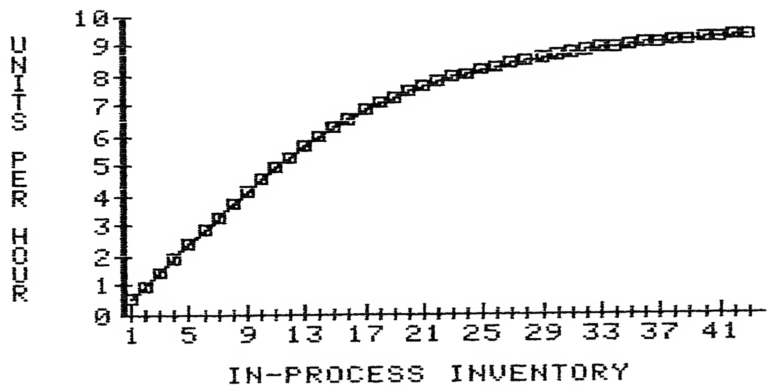

FIG. 5. PRODUCTION RATE

propriate for long range decisions, but may be misleading over the short run. Finally, it simply does not address some of the more detailed issues, such as scheduling priorities at individual stations. For these issues, which occur at a later stage in the system designs, we advocate the use of simulation.

OPEN RESEARCH ISSUES

Despite the success we have had with CAN-Q and with simulation methods, there remain a wide variety of manufacturing system design problems which are in need of analytical aids. That is, we can presently deal with them only awkwardly, if at all, using the methods we have.

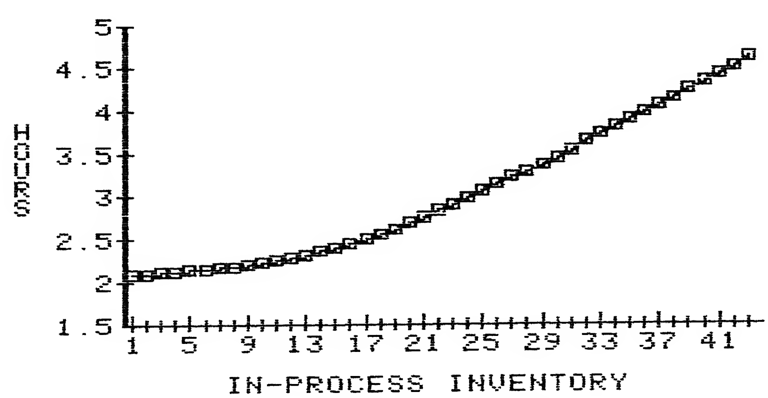

FIG. 6. FLOW TIME

One general research area has to do with the sizing and location of buffer storage. The theory underlying the CAN-Q model assumes adequate storage wherever it is needed and cannot be modified to show the constraining effects of inadequate or misplaced storage. Through simulation, one could of course compare a number of alternatives, but the number of combinations of possibilities precludes complete treatment by this method. Analytical results are known for special cases, such as two machine and three machine flow shops, but no practical general methods are available. With the increasingly expensive and tightly interdependent automated manufacturing systems being designed today, the proper handling of in-process inventory has become a critical issue.

Another practical need is for analysis methods to deal with the effects of shared resources, such as tools and fixtures. In earlier systems, each machine would have its own set of tools, so (barring failures) the tools needed for an operation were available. There is a trend now to store tools centrally and transport them as needed to individual machines using either a special transport system or the same one as that which moves the work pieces. This practice introduces an additional level of resource contention, in that an operation may be delayed even though the machine and workpiece are ready because the necessary tool is in use elsewhere. Of course, multiple copies of a tool may be provided if the problem is severe, but complete duplication would defeat the purpose of the common pool. We need methods to explore the tradeoffs. We have been working on this problem at Purdue for the past year, with some degree of success. Our major finding, however, is that the problem is considerably more difficult than it appears to be; some of our favored approaches failed utterly.

There is still a large gap between the theory and practice of scheduling. It is not just a communication gap or an implementation lag, but a genuine lack of results for real problems. The recent clarification of the computational complexity of many of classical scheduling problems found in the literature -- problems which are generally much simpler than the real problems found in industry -- merely accentuates the need for fresh approaches. Certainly we cannot abandon the whole area to the kinds of ad hoc procedures which are devised by system programmers today.

Finally, there is a great need for integration of modeling methods. As one proceeds from aggregate analysis, such as that performed by CAN-Q, through more and more detail down to the level of control system design, one ought to be able to make smooth transitions. It should not be necessary to start over with new data formats, conventions, and terminology at each step. This issue may appear to be more a matter of agreement upon standards than an area for research, but I would suggest that we are currently so far

from even being able to discuss standard interfaces for mathematical models that the issue is indeed a subject for research.

ACKNOWLEDGEMENTS

The National Science Foundation funded the research under which CAN-Q was originally developed (Grant APR74 15256) and later extended (Grant DAR78 26567).

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ANALYSIS OF FLEXIBLE MANUFACTURING SYSTEMS

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INTRODUCTION

Definition

What is a flexible manufacturing system (FMS)? Briefly an FMS is an "automated job-shop", or more diffusely an FMS is a set of machines connected by a transport network, capable of producing a variety of related parts with a minimum of manual intervention.

The definition for an FMS would require that it contain:
1) computer-controlled machine tools capable of being programmed to change tools or heads, and capable of stand-alone operations;
2) a materials handling system which automatically moves parts randomly between stations, controlled by a computer or programmable controller
3) an executive or host computer, with these functions:
- storing parts programs for downloading to machines
- handling the scheduling of parts to machines
- collecting management information.

The operations of an FMS are:
- workpieces are placed on fixtures, usually by manual loading
- fixtures circulated on carts and/or pallets to different machines as directed by a central computer
- NC programs are downloaded from a central computer to the appropriate machines
- machined workpieces are unloaded, usually manually.

FMSs have recently been introduced in effort to increase the productivity of that sector of industry that produces a medium volume of a set of related parts. Annual production ranges from 200 to 20,000 parts per year (Hughes et al., 1978), which is not high enough to warrant use of a set of dedicated transfer lines. On the other hands job shops suffer from a low utilization of expensive machines and a high in-process inventory.

Advantages

An FMS must be able to reorganize production in front of external demand variations or inside failures, to maintain the highest utilization of machines (capital investment). Main advantages are

- flexibility to quantity of demand
- flexibility to diversity of demand
- graceful degradation in case of failed machines.

Flexibility to diversity of demand, allows to invest over time only in new products like fixtures, tools and programming which are quick perishable.

Slow adoption of FMS in industry

Notwithstanding the existence of apparent benefits for low-mid range production, potential users are not adopting FMS technology rapidly. Depending how broad the FMS definition is, only 25 to 100 systems were installed worldwide at the beginning of 1981 (McGinty, 1981). Despite traditional FMS hardware, selection of the type of plant, planning of parts to be produced, plant management and maintainence, require decisions which cannot be only supported by experience. On the other hand a 'decision supporting software' is not yet mature; the most usual aid in supporting decision being simulators.

Research on FMS

Due to complexity of the system and the relative novelty of FMS, research on the subject has been concentrated mainly on modelling and optimization of the material flow (Buzacott and Yao, 1982). Extensive simulation studies of FMSs have been made. Recently, hybrid analytical/simulation models have been proposed to collect more information from a single experiment (Ho and Cassandras, 1980). Several analytic models of FMSs have been based on a network-of-queues approach (Suri, 1981), they have been used to optimize part routing (Kimemia and Gershwin, 1980).

One of the preminent optimization problems in EMS like in job-shops is to find an ordering of jobs on machines which meets some objective (deterministic scheduling). A tremendous amount of research has been done covering most circumstances. The contribution the research has made, is to assure that optimal seeking methods for job-shops very likely do not exist (NP-complete problems). Tentatives of applying deterministic scheduling to FMSs are very few, mainly through heuristics (Hitz, 1980; Kanellakis, 1978).

Only recently the problem of flow optimization in FMSs has been attempted through hierarchical decomposition (Kimemia, 1982; Hildebrandt, 1980). In their formulation FMSs prone to failure are considered. At a more operative stage, C.S. Draper Laboratory is implementing a decision support software for FMS design and control based on a hierarchical decomposition (1981) . A methodology for decomposing into different levels FMS scheduling is presented by Hildebrandt and Suri (1980).

Scope of this note

Recent advances in FMS optimization have been mainly directed to the real time control in the presence of failures. Very small work has been done to our knowledge in finding stationary configurations of these systems in terms of resource allocation and part scheduling, which satisfy a system objective. The interest for such solutions are different:

- from a theoretical point of view the problem is still complex, and requires a multi-level approach as in the non deterministic case
- production target can be partitioned in short time batches, to render system MTBF large in comparison of production horizon time
- at the design stage usually failures are taken into account implicitly through availability indices.

FMS optimization is formulated mainly as a resource allocation problem, where resources to be optimized are machines, buffers, fixtures. The problem splits naturally into four level, routing and scheduling decisions being at the lowest levels. The method of decomposition is partly based on the ideas expressed in Suri(1980).

STATEMENT OF THE PROBLEM

A formal statement of the problem requires specification of a model and an objective.

System model

Following partially the terminology of Coffman(1976), the system model is comprised of three parts.

1) Free resources, to be optimized
   a) Set M of machine types, indexed by $m = 1,\dots,\bar{m}$. Once the number ν_m of machines 'm' has been selected, the index $j=1,\dots,J$ denotes a single machine, such that $J = \sum_m \nu_m$ and $j(m)$ a machine of type m.
   b) Set F of fixture types, indexed by $f=1,\dots,\bar{f}$. Once the number μ_f of fixtures 'f' has been selected, the index $r = 1,\dots,R$ denotes a single fixture, such that $R = \Sigma_f \mu_f$.
   c) Transport network. A set N of nodes, indexed by $n = 1,\dots,\bar{n}$ and a set L of links, indexed by $l = 1,\dots,\bar{l}$; generally four types of links exist
      - input links
      - output links
      - links between a pair of nodes comprising a machine
      - bypass links.

      To every link 'l' is allocated a storage space b_l measured in number of fixtures; $B = \Sigma_l b_l$.
2) Constrained resources

   Tool set U, indexed by $u = 1,\dots,\bar{u}$. The number of tools on each machine type m is constrained by the number s_m of available slots.
3) Tasks
   a) Set P of part types, indexed by $p=1,\dots,\bar{p}$. Each part type p must be produced in the ratio q_p to the total production volume; i.e. $\sum_p q_p = 1$. The 'minimal part set' is defined as the set of integers $\{\bar{q}_1,\dots,\bar{q}\}$ satisfying $\bar{q}_p = \alpha q_p$ and such that α is minimized. Single parts to be produced are indexed by $i=1,\dots,\alpha$.
   b) Set O_p of operations per part p indexed by $o(p) = 1,\dots,\bar{o}(p)$.

      Each operation o(p) requires to be completed a machine dependent time $\tau_{o(p),m}$; $\tau_{o(p),m} = \infty$ if the operation cannot be performed on machine m. Each operation o(p) is assigned a distinct tool $u \in U$ through a zero/one matrix C. A precedence relation is allowed between operations of a part.

System objective

Find system control variables including
- part operations allocation to machine types
- routing of parts through machines

- part volume allocation to single machines
- ordering of parts entering the system

which minimizes free resources, i.e.

- the total cost of machines
- the total cost of the fixtures
- the number B of storage spaces

while maintaining

- the target of producing the minimal part set $\{ \bar{q},\ldots,\bar{q}_{\bar{p}},\alpha\}$ in a time horizon $\bar{T}$
- tool capacity constraints
- operation precedence.

Remark. Such objective formulation would require a system redesign every modification of production target $\{ \bar{q}_1,\ldots,\bar{q}_{\bar{p}},\alpha, \bar{T}\}$. One of the major features of FMS is the possibility of adapting system layout to varying production targets. However in actual FMSs, layout is assumed to change only after periods much longer than $\bar{T}$, and during such periods production target is continuously varying. Thus problem solution should allow

- a priori design for different production targets,
- on-line redesign of system configuration with some earlier free resources (machines, transport network) constrained.

Due to formidable complexity of the problem both specifications can be met only by a multi-level decomposition.

System control variables

Scheduling or layout problems for network of machines are usually NP- complete (Gershwin et al., 1980); hierarchical structures which lead to acceptable amount of computation have been suggested by some authors (see Hildebrandt and Suri, 1980).

Preliminary is the decomposition of the set of control variables D into a cartesian product

$$D = D_1xD_2xD_3xD_4 \tag{1}$$

where

$D_1 = \{ \pi = (\pi_{11},\ldots,\pi_{pm},\ldots)$: vector of the sequences π_{pm}, including the operations of the part p allocated to type m $\}$

$D_2 = \{ x=(x_{11},\ldots,x_{pj},\ldots)$: vector of number of parts p allocated to machine j $\}$

$D_3 = \{\rho = (\rho_1,\ldots,\rho_p,\ldots)$ vector of the sequences ρ_p of ma-

chines allocated to part p}

$D_4 = \{\sigma : \sigma =$ sequence of parts entering the system $\}$.

Then every control variable is defined by the quadruple

$$\omega = (\pi, x, \rho, \sigma) \qquad (2)$$

Problem aiming at the selection of a control variable in each set D_k, have well established names:

D_1 : operation allocation
D_2 : part allocation
D_3 : routing
D_4 : scheduling.

Modelling resource constraints

1) Time constraint

Denote with T_j the completion time of a machine j : j=i,...,J . It must satisfy

$$T_j \leqslant \bar{T}, \forall j \qquad (4)$$

To model T_j the control variable decomposition (2) is exploited, bringing to :

$$T_j = \sum_p [T^\circ_{pm}(\pi) + T''_{pm}(\pi, x, \rho) + T_{pm}(\pi, x, \rho, \sigma)\, x_{pj} + T'_j(\pi, x)$$

where

- $T^\circ_{pm} = \sum_{o(p) \in \pi_{pm}} \tau_{o(p),m}$ is the completion time of a part p on a machine m;
- $T_j'(\pi, x) = \beta_j(\pi, x)\gamma_j$, is the tool change time forced by the limited tool capacity on each machine; $\beta_j(.)$ is the number of tool changes and γ_j is the time to change tool set;
- $T''_{pm}(\pi, x, \rho)$ model waiting times in front of machine m due to unbalancing of times T°_{pm} and the routing ρ_p ;
- $T'''_{pm}(\pi, x, \rho, \sigma)$ models waiting times in front of machine m due to and scheduling of parts.

Remark. Uncertainty of times

In our analysis any randomness of operation and waiting times is neglected; since we are interested in finding a stationary configuration of the FMS, unpredictable failures of machines, material handling system or any other FMS part, are not modeled. As a justification we could assume that such events have an MTBF very large in comparison to the horizon time T; thus failure modeling being the concern of a

transient analysis which is beyond the scope of this note. Instead, preventive maintainance may be taken into account through a fixed time d_j for each machine. In this context a key problem is the modeling of T'_j, T''_{pm} and T'''_{pm}, which possess a large uncertainty due to complexity of problem.

2) Tool constraint

Tool sharing is possible only within a machine. Let $y_{o(p),m}$ be the zero-one decision of allocating the operation o(p) to the machine type m; then

$$y'_{o(p),j} = \begin{cases} 0 & \text{if } y_{o(p),m} x_{pj} = 0 \\ 1 & \text{otherwise} \end{cases} \tag{6}$$

is the decision of allocating the operation to the actual machine j of type m. Further define

$$z_{uj} = \begin{cases} 0 & \text{if } \sum_p \sum_{l(p)} y'_{o(p),j}\, c_{o(p),u} = 0 \\ 1 & \text{otherwise} \end{cases} \tag{7}$$

Then

$$\sum_u z_{uj} \leqslant (\beta_j + 1) s_j \quad , \forall j \tag{8}$$

Such constraint looks very hard, due to (6) and (7).

3) Convexity constraint

$$\sum_j x_{pj} = \bar{q}_p , \forall p \tag{9}$$

STRUCTURE OF THE SOLUTION OF FMS PROBLEM

Hierarchical structure

The layout and scheduling problem of FMS is formulated as

$$\begin{aligned} &\min_{\omega} \sum_m \nu_m c_m \\ &\min_{\omega} \sum_l b_l \\ &\min_{\omega} \sum_f \mu_f d_f \end{aligned} \tag{10}$$

subject to

- time constraints $T_j \leqslant \bar{T} \quad , \forall j$
- tool constraint $\sum_u z_{uj} \leqslant (\beta_j + 1) s_j \ , \forall j$.

- convexity constraint $\sum_j x_{pj} = \bar{q}_p, \forall p$

A hierarchical structure is proposed for solving the problem. At each level k an optimal control variable ω_k^* is selected in D_k on the base of a level objective $L(\omega_k)$; a usually sub-optimal solution $\hat{\omega}$ for the problem (10) is built by concatenation

$$\hat{\omega} = (\pi^*, x^*, \rho^*, \sigma^*) \tag{11}$$

The formulation of a level k problem requires

1) prediction
2) aggregation

of the lower level variables. Prediction is usually implicit and requires experience and intuition.

<u>First level - operation allocation</u>

1) Prediction of times
   a) Routing and scheduling delays, T''_{pm} and T'''_{pm} :

   neglecting transport times and waiting times due to shortage of fixtures, it is easily shown that

$$0 \leqslant \bar{T}_{pm} = T''_{pm} + T'''_{pm} \leqslant \max_{\underline{m}} \{ T^\circ_{p\underline{m}} \} - T^\circ_{pm} = \bar{T}_p - T_{pm} \tag{12}$$

   Assume that every part p has the same completion time, say $\bar{T}_p$, on each machine it visits; in this case modifying routing or input sequencing does not cause any additional delay. Thus uncertainty on waiting times is reduced by balancing times T°_{pm} for every part p. Typically $\bar{T}_{pm}$ is a convex function $\varepsilon_{pm}(.)$ of the difference $\delta_p(\underline{m},m)=T_{p\underline{m}}-T_{pm}$, for a routing $(\underline{m},m)$; $\varepsilon_{pm}(.)$ should not be even to take into account the benefits of an appropriate routing. At this stage $\bar{T}_{pm}$ can be modeled simply as a constant $\bar{\varepsilon}$ pm (magnitude of operation time), providing

   1) operation allocation balances T°_{pm}
   2) routing and scheduling reduce $\bar{T}_{pm}$.

   b) tool change time:

   We assume that tool change times γ_j are negligible with respect to the completion times on each machine for the minimal part set α; if this would not be the case, it is sufficient to allow a number n of minimal part set such that γ_j/n is still negligible. The optimization of $\underline{n}$ is a higher level problem, involving the production horizon $\bar{T}$. Thus tool constraint can be taken into account by an estimate $\hat{\beta}_j$ of the number of changes, which can be predicted by a side-optimization problem not mentioned here.

2) Aggregation of part allocation
As this stage single machines are not recognizable, thus x_{pj} variables can be aggregated using convexity constraint.

3) Master and slave problem
By previous modeling the first level splits into a sequence of two problems

a) Master - Resource optimization

$$\min \sum_{n} c_m \nu_m \tag{13}$$

subject to $\sum_p \left(\sum_{o(p)} \tau_{o(p),m}\, y_{o(p),m} + \bar{\varepsilon}_{pm}\right) \bar{q}_p \leqslant \nu_m(\bar{T} - \hat{\beta}_m \gamma_m)$

$\sum_m y_{o(p),m} = 1$

precedence between operations

where $y_{o(p),m}$ is a zero-one variable and ν_m is integer.

This is a large integer optimization problem but can efficiently solved by a three level decomposition:

- solve for fractional ν_m, neglecting precedence between operations, using the gradient of $y_{o(p),m}$; we obtain the least cost J_1 and fractional ν_m
- arrange precedence relations with least degradation of new cost $J_2 > J_1$
- find integer ν^*_m to minimize the degradation of J_2; it could require a reallocation of operations.

b) Slave problem - Balancing times T°_{pm}

Due to integer value of the optimal ν^*_m, time constraint is likely to be slack. This allows balancing part completion time T^o_{pm} to facilitate routing and scheduling in maintaining the prediction of $\bar{T}$.

Denote with $\delta y_{o(p),m}$ a variation of the optimal decision $y^*_{o(p),m}$, solution of the master problem, with values (-1,0,1).

We formulate balancing as

$$\min \sum_p T_p \tag{14}$$

subject to

$$\sum_p \left(\sum_{o(p)} \tau_{o(p),m}\, \delta y_{o(p),m}\right) \bar{q}_p \leqslant \nu^*_m (\bar{T} - \hat{\beta}_m \gamma m) - \overset{*}{T}_m$$

$$\sum_{o(p)} \delta y_{o(p),m} = 0$$

$$\sum_{o(p)} \tau_{o(p),m}\, \delta y_{o(p),m} \leqslant T_p - \overset{*}{T}_{pm}$$

precedence relations

where $\overset{*}{T}_m = {}_p(\overset{*}{T}_{pm} + {}_{pm})\, \bar{q}_p$ and $\overset{*}{T}_{pm}$ is the master solution.

Second level - Part allocation

To find the objective at this level assume a perturbation in the number of machines decided at previous level, say, due to a failure. Then in a tentative of satisfying the production horizon $\bar{T}$, parts must be reallocated by minimizing the completion time of each machine T_j. As a secondary objective part allocation should maintain the prediction of tool changes $\hat{\beta}_j$ formulated at the first level.

The minimum time objective can be formulated as

$$\begin{aligned} & \min \; T \\ & \text{subject to} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (15) \\ & \sum_p (T^*_{pm} + \varepsilon_{pm})\, x_{pj(m)} + \beta_{j(m)}\gamma_m \leqslant T \\ & \sum_j x_{pj} = \bar{q}_p \\ & x_{pj(m)} = 0 \;\; \text{if } T^*_{pm} = 0 \end{aligned}$$

where $\beta_{j(m)}$ is the number of tool changes to be maintained near $\hat{\beta}_m$.

Instead of finding an explicit expression of $\beta_{j(m)}$ as a function of x_{pj}, a very difficult task, heuristic precedence rules based, e.g. on the percentage of common tools, can be devised.

Third level - Routing

Routing optimization is very dependent on the possibility of selecting different routes between machines. Usually FMS's do not have a network of links connecting different machines; instead machines are disposed on bypass links, connected to a closed conveyor. In this case only one shortest route exists visiting all machines in a cycle; other routes can be created or by visiting less machines or by allowing more cycles around conveyor and hence longer travel times.

Accepting the above layout the routing problem splits into
- a layout problem: find the best ordering $\bar{\rho}$ of machines around the conveyor
- a true routing problem: to find for every part the sequence ρ_p of machines to be visited.

Layout problem. A natural objective, as dictated by the system objective, would be the minimization of the storage space around the transport network. However higher levels dictate that the predicted waiting times should be preserved. To formulate the problem, parts are aggregated and a single storage space b_j per machine is assumed. Denoting with ε_j'' the aggregated waiting time to be preserved and $\eta_j(b_j, \bar{\rho})$ the actual cumulative time and with $\lambda_j > 0$ a suitable weight, the optimization problem is formulated as

$$\min_{\bar{\rho}, b_j} \sum_j (b_j + \lambda_j \| \eta_j (b_j, \bar{\rho}) - \varepsilon_j'' \|^2) \tag{16}$$

subject to $b_j \geq 0$, $b_j \leq \bar{b}_j$

precedence relation between machines.

The optimal ordering $\bar{\rho}^*$ in the complete ignorance of η_j is to order machines with decreasing completion times T_j^* , computed at the second level; account taken of precedences.

Routing problem. Routing of single parts benefits of a fixed layout. The objective is to maintain the predicted waiting times ε_{pm}''. Thus we formulate the problem

$$\min_{\rho_p} \sum_p \sum_m \| \hat{\eta}_{pm}(\rho_p) - \varepsilon_{pm}'' \|^2 \tag{17}$$

where $\hat{\eta}_{pm}(\rho_p)$ is the actual waiting time, function of the layout decisions b_j^* and $\bar{\rho}^*$.

A suboptimal ordering is to accept $\bar{\rho}_p = \bar{\rho}^*$; a trade-off arising between transport and waiting times. Such trade-off is likely to arise if the size of storage space has been underestimated at the layout stage.

Fourth level - Scheduling

The objective dictated by higher levels is to preserve the predicted waiting times $\varepsilon_{pm}'''(\pi^*, \rho^*, \sigma)$ due to scheduling . Due to complexity of problem we try to make some light considering two extreme cases. Our reasoning will be based on the cumulative production curves of every machine, which is the locus of points (n, t), where n is the cumulative number of produced part and t the cumulative operation time, both depending on σ. Such curves are montonic

increasing. They grow around the mean production straight line of slope n_j/T_j, with n_j the total number of parts produced. Waiting times are caused by interference between such curves.

To minimize interference they must follow as much possible the mean production line.

Independent supply of machines. It requires a central storage but permits giving production curves the least possible dispersion. This is an ideal case, with the disadvantage of high in-process inventory.

Uniform routing. The opposite case happens when the same routing has been selected for all parts. The situation is more intriguing, but interesting to say, an algorithm which looks for the least interference exists; it is not included here.

DISCUSSION

The most apparent fact is that the decomposition proposed is highly dependent on the modeling of waiting times. In the nondeterministic case Mean value Analysis is largely used (Hildebrandt and Suri, 1980). Could it work also in deterministic case by considering a fictitious distribution of part completion times for every machine? A further point to be investigated are the convergence properties under iteration betwen levels.

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SIMULATION OF PRODUCTION SYSTEMS WITH DESFOR

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ABSTRACT

This paper presents the analysis of a production system by making use of the discrete event simulation package DESFOR developed by the authors. DESFOR is a FORTRAN based package oriented to the simulation of discontinous systems. Its approach to simulation follows the method known as "process view of simulation" that relies on concurrent programming techniques. Linguistic constructs in DESFOR allow to model standard components of plants, such as workstations and storages with the automatic collection of relevant statistics. The analysis of the production system consists of two main levels: the high level schedules the sequences of parts to be introduced into the system according to a performance objective and makes use of simplifying assumptions that will be tested in detail on the low level plant simulation model.

INTRODUCTION

The value of simulation in the analysis and design of production systems is universally recognized. In fact many papers, such as those by Hutchinson[1] and Tavalage[2] witness the successful use of simulation as a flexible and economic support to the analysis of existing systems for improving productivity.

Most simulation models are written in specialized computer languages: GPSS[3], SIMSCRIPT[4], GASP[5] and SIMULA[6] are the major ones. Such

languages are based on different simulation methods as Fishman[7] illustrates, anyhow they provide the user with a set of constructs helping him, in different ways according to the language used, to represent the model of the system to study and to collect and process relevant informations during the simulation. Most of mentioned languages are available only on large computers.

Recently a new trend has appeared tending to extend general purpose languages, such as PASCAL and FORTRAN, with simulation primitives [8,9] : the main advantage, this proposal involves, is the immediate and wide availability of simulation facilities that are no longer bound to specialized languages.

The method known in literature as "process view of simulation" inspired such extensions. This method, being based on concurrent programming techniques, is growing in popularity and lends itself to be conveniently applied[11] to real time programming languages,such as Ada[12], exhibiting native parallelism features.

The above-mentioned extension[9] to FORTRAN, developed by the author, gave rise to the discrete event simulation package DESFOR[13] to be illustrated in this paper. DESFOR features:

- quasi-parallel programming; in fact the simulation program is decomposed into quasi-parallel processes (or coroutines);
- predefined constructs for modelling interactions among processes, such as competitions for acquiring limited resources, exchanges of items through limited buffers and so on; such constructs are similar to those added to SIMULA by DEMOS[14];
- random number generation and collection and printing of statistical data.

DESFOR differs from other FORTRAN based simulation packages, such as GASP and GPSS-FORTRAN[15] because of the different approach to modeling it relies on. Another consideration concerns portability. The aim of modelling by using concurrent processes cannot be attained in a sequential language without modifying the compiler or introducing some assembly routines. Therefore DESFOR is a collection of FORTRAN subroutines plus two assembly routines, whose overall length in the PDP 11 assembly language is of ten instructions.

This paper has the following organization. At first the package DESFOR is illustrated and some methodological considerations are also made. Then its use in the modelling of a flexible manufacturing system is discussed.

DESFOR FEATURES

This section deals with modelling techniques and implementation details of the discrete simulation package DESFOR. A preprocessor is associated with DESFOR, so that calls to simulation primitives are substituted by more readable statements beginning with a period, as will be shown in following examples.

Modelling techniques : processes and entities

The model of the system to simulate is decomposed into a set of simultaneous activities, or processes, each of which describes the behaviour of a system component. For instance let us consider a multi-user system with a single resource. If the phenomenon we are interested in, is the queueing of users for acquiring the resource, then the behaviour of each user can be concisely described by a separate piece of program (i.e. a process) performing the cyclic sequence of actions: doing something for a period of time, requesting the resource,holding it for some time and releasing it. In this example users are not independent of one another but interactions arise when they request access to the resource. The language has to facilitate the modelling of such interactions by providing ready-made constructs for representing them. Therefore processes interact one another indirectly by performing operations on objects that in the remainder will be referred to as entities. The use of entities simplifies the writing of programs and hides implementation details; furthermore it involves the automatic collection of statistics as will be shown later.

Implementation details : processes and events

Each process declaration may originate several instances, each of which is characterized by individual parameters assigned at generation. A unique descriptor is associated with each instance for keeping its current state. Simulation primitives operate on instances indirectly through the informations contained in their descriptors. The terms process and instance will be often used as synonymous when that causes no confusion.

In discrete event simulation the concept of event is fundamental: it is now presented according to the process view of simulation. Because of the discontinuous nature of simulation, the activity of each process concentrates in particular instants, or events, during

its life. The transition from an event to the next one implies the elapsing of some period of simulated time, whose duration is not always known in advance. In fact such a duration is known when the process spontaneously delays itself for a certain interval of time, but the exact occurrence of the next event cannot be foreseen when it is dependent on the occurrence of an event in the life of another process. In both cases the execution of the process is abandoned and it enters a period of inactivity while waiting for the occurrence of its next event. The process is said to be delayed or suspended respectively, according to the above-mentioned distinction. The simulation evolves with asynchronous timing, because when the system has processed an event, it proceeds to the next one, whose occurrence time updates the simulation clock. Since the executions of processes are actually intermixed, informations about inactive processes are saved into <u>queues</u>.

Queues are fundamental structures used to keep descriptors of inactive processes. In particular the <u>event queue</u> containing future events with known occurrence times, is actually implemented as a queue of process descriptors ordered according to increasing resumption instants. Queues are the basic elements for building any kind of process interaction mechanism as will be shown later.

<u>Basic primitives</u>

The management of processes, as previously illustrated, is based on the following basic primitives that are now informally presented.

a) Delay T : the calling process is to be delayed for T units of simulated time; its descriptor is put into the event queue.

b) Suspend : the calling process is to be suspended; a process invokes this primitive after storing its descriptor in a queue,so that it can be resumed later.

c) Resume D : the process identified by descriptor D is to be resumed; D has been taken from some queue; this primitive places D at the top of the event queue.

The use of primitives delay and suspend involves a <u>process switching</u>, that is control is transferred from the calling process to the first process in the event queue. The resumption instant of such a process updates the simulation clock, too.

Processes are executed in a quasi-parallel way, because their executions are intermixed. A process resumes its execution at the statement following the point of suspension, therefore it cannot be represented as a simple subroutine, but it needs the coroutine behaviour. In fact each process instance possesses private stack and stack pointer that are manipulated when the instance is generated and when a process switching occurs, by means of two assembly routines.

Implementation of entities

Entities can be considered abstract data types: operations on them carry out common process interaction mechanisms and help the user to collect statistics about quantities of interest depending on the entity type. Four types of predefined entities are implemented : resources, rendezvous, buffers and counters.

Resources model objects available in a limited amount. They are equivalent to facilities and storages in GPSS. Each resource comprises a queue for keeping descriptors of waiting processes. Collected statistics include: the average number of waiting processes, the maximum length of the queue, the average waiting time and the utilization of the resource. The example of fig.1 illustrates two processes, PROC1 and PROC2, competing for acquiring resource n.1. The diagram shows how interactions between the processes take place and how the simulated clock advances through their alternate suspensions and resumptions.

A rendezvous allows two processes to cooperate for a lapse of time in order to accomplish a common task. According to DEMOS it is convenient to consider one process as a master and the other as a slave during the period of collaboration. The rendezvous between the processes is carried out by procedures COOP and JOIN that are called by the master and the slave respectively. When both are executed only the master process continues until it requests procedure FREE that resumes the slave process. From then onwards processes go on independently (cf. fig. 2). Each rendezvous entity consists of two queues containing descriptors of master and slave processes waiting for their partners. Statistics concern the average duration of cooperations and the average number of waiting master and slave processes.

Buffers allow interactions between processes producing messages and processes consuming them (cf. fig.3). Statistics are collected

about the average number of messages in buffers and the average waiting times of producers and consumers.

Counters differ from buffers because no physical messages are sent but only signals (cf. fig.4).

```
.PROCESS     PROC1          .PROCESS    PROC2
    ...                         ...
1   .DELAY     10.0         1   .DELAY     15.0
2   .REQUEST    1           2   .REQUEST    1
3   .DELAY     10.0         3   .DELAY      5.0
4   .RELEASE    1           4   .RELEASE    1
    ...                         ...
```

The behaviour of each process is quite simple: after an initial delay it requests resource n.1, when it has got it, it holds it for some time then releases it.

Simplified process descriptor: $\quad {}^{A}(B,C,D)$,
where A is the descriptor identifier, B is the resumption instant, C is the symbolic number of the instruction to be executed at resumption and D is a pointer to the next descriptor identifier in the queue where the current descriptor is. Let us suppose that 1 and 2 are the descriptor identifiers corresponding to PROC1 and PROC2 respectively. The following diagram shows the contents of queues immediately before a process switching.

Simulated time	Event queue	Resource n.1 queue
0.0	${}^{1}(10.0,2,2)\ {}^{2}(15.0,2,0)$	
10.0	${}^{2}(15.0,2,1)\ {}^{1}(20.0,4,0)$	
15.0	${}^{1}(20.0,4,0)$	${}^{2}(\quad ,3,0)$
20.0	${}^{2}(25.0,4,0)$	
25.0	End of simulation	

Figure 1. Interaction diagram of two processes competing for a single resource.

Queues can be used to build general frorm of interactions among processes. For that purpose it is necessary to associate a queue with a condition. Then a process evaluating the condition can suspend itself, if it is false, in the corresponding queue by performing a WAIT operation. The process remains in the queue until it is awakened by another process executing a SIGNAL operation; then it can again test the condition (cf. fig.5).

```
.PROCESS MASTER            .PROCESS  SLAVE
   ...                        ...
   .COOP   1                  .JOIN 1
   .DELAY  T                  ...
   .FREE   1
   ...
```

Figure 2. Interaction through a rendezvous entity.

```
.PROCESS   PROD            .PROCESS  CONS
   ...                        ...
   .PUT    1,M                .GET   1,M
   ...                        ...
```

Figure 3. Interaction through a buffer entity.

```
.PROCESS   PROD            .PROCESS  CONS
   ...                        ...
   .INC    1                  .DEC   1
   ...                        ...
```

Figure 4. Interaction through a counter entity.

```
.PROCESS   TESTER          .PROCESS  SIGNALLER
   ...                        ...
1  IF(COND) GO TO 2           COND = .TRUE.
   .WAIT    1                 .SIGNAL 1
   GOTO     1                 ...
2  CONTINUE
   ...
```

Figure 5. A general form of interaction.

SIMULATION OF A FLEXIBLE MANUFACTURING SYSTEM

This section illustrates the analysis and the scheduling of a flexible manufacturing system that is being carried out with the aid of the package DESFOR. Since the seeking of an exact solution of the scheduling problem is impractical, due to the complexity of the system, an interactive approach consisting of three software levels is being followed.

At the bottom level the model of the plant written in DESFOR is able to simulate the flow of parts through the system and to collect performance data such as machine utilizations.

The top level is responsible for elaborating the scheduling of operations on machines; it makes simplifying assumptions for reasonably taking into account constraints such as the limited availability of fixtures and tools. Heuristic schedules generated at this level will be tested on the plant model.

The middle level controls the execution of the schedule determined at the top level by injecting part batches into the model.

In the remainder of this section each level will be discussed in detail after a brief illustration of the plant.

Plant description

The flexible manufacturing system depicted in fig.6 consists of a group of workstations interconnected by a circular conveyor. The classification of workstations is as follows: M1 is a vertical lathe, M2 - M5 are identical machining centers, M6 and M7 perform auxiliary operations (washing and drying of parts) and L/U is the load/unload station where manual intervention takes place. Most machines possess one-place input and output buffers that shuttles connect to the conveyor. Each machining center has a tool magazine containing up to 65 tools.

The system has to manufacture 25 different kinds of parts in a given production mix. Most part types require only one operation to be performed on a machining center (M2 - M5), others need two operations, the first on the lathe (M1) and the second on a machining center, a few types are to be processed only by the lathe.Some kinds

of workpieces are to be machined in two or more positions; this is taken into account by associating different part types with the same workpiece, each part type corresponding to one of the possible machining positions.

Each part is mounted on a fixture for ease of handling and accurate machining. The loading and unloading of fixtures are performed by an operator at the L/U station. Fixtures are carried through the plant on pallets. The attachment of fixtures to pallets take place outside the system.

Plant simulation level

The plant model includes the following data:

a) information on part types such as working times on machines, fixture types and precedence constraints;
b) travelling times associated with conveyor segments.

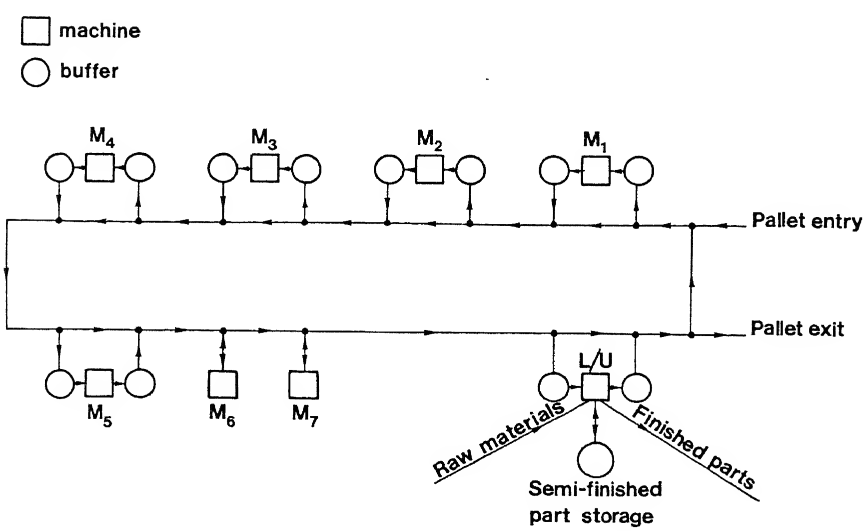

Figure 6. Lay-out of a flexible manufacturing system.

Since pallets are the active components of the simulation, they are represented as instances of the same process PALLET. Each instance is characterized by private parameters containing:

a) the reference to the part type currently being associated with it;
b) the eventual specification of the machining center it must go to for service;
c) the indication of the presence or absence of a part on the pallet;
d) the current length of the batch the pallet is assigned to.

The behaviour of each pallet is characterized by the following phases.

1. An empty pallet enters the system through the pallet entry (cf. fig.6): it carries a fixture and its parameters have been set up.
2. It goes to the L/U station where it is loaded with a part corresponding to the fixture it carries.
3. The pallet visits workstations according to its part type; in particular if the part requires a machining center, the pallet goes to that specified in its parameter.
4. When operations are completed the pallet moves to the washing and drying stations and then to the L/U station where the finished part is removed.
5. At the L/U station the current batch length associated with the pallet is decremented and if the result is positive a new part is mounted on the pallet that continues in phase 3. Otherwise two cases can occur:
   a) the pallet is assigned to a new batch requiring the same fixture as the finished one by re-initialization of its parameters;a new part is mounted on the pallet that continues in phase 3;
   b) the pallet remains empty, so it will leave the system through the pallet exit (cf. fig.6).

The access to a workstation takes place as follows. A pallet is drawn from the conveyor by the input shuttle and is put into the machine input buffer where it waits for being machined. If the input buffer is already occupied the pallet can stop and wait on the conveyor segment near to the workstation or it can proceed either to a new destination or to the old one by going round the plant. Once machining is completed, the pallet enters the machine output buffer and either immediately or after a certain time it is put again onto the conveyor by the output shuttle. From the above description it is evident that some decisions are to be taken when the input buffer is full or when a part is to return on the conveyor. Such decisions are taken by the supervisor to be illustrated in the next subsection.

Machined parts are assumed to be taken away from the system at the L/U station with the exception of parts corresponding to workpieces machined in more than one position. Such parts are stored as semi-finished materials (cf. fig.6). Raw materials are also assumed to be available without limit at the L/U station.

The model of the plant makes use of the following predefined DESFOR entities: 50 resources, 10 counters, 15 queues associated with conditions.

Supervision level

The supervisor is responsible for the carrying out of the schedules generated by the planning level according to the availability of pallets and fixtures. It controls the admission of pallets into the system and assign them parameters, but most of its activity takes place in responding to signals received from the plant simulator. Such communications occur in the following cases:

a) when a pallet enters the washing station carrying the last part of a batch; this signal can synchronize the injection of a new pallet into the system;
b) when the last part of a batch is removed from a pallet at the L/U station;
c) when a pallet cannot enter the input buffer of its destination because it is already occupied;
d) when a part enters the output buffer of a workstation.

The management of the first two cases can involve the starting of a new batch, while the management of the last ones depends on the policy being adopted at the planning level as will be shown in the next subsection.

Planning level

The aim of the planning level is to schedule operations on workstations in order to meet the required production for each part type in a given period of time and to minimize the total amount of fixtures.

Such an objective is affected by the following factors:

a) priorities among parts originating from different working positions of the same workpiece and buffering capabilities for semi-finished parts;

b) aspects concerning tools: tool requirements for each part type;
tool magazines with limited capacity;
tool wear;
machine interruptions for tool change.

To obtain reasonable schedules with an acceptable amount of computation a simplifying assumption is being made, whose effects will be tested in detail on the plant model. This assumption involves to neglect interactions among parts on the conveyor and at workstations M1 and L/U, and to perform the scheduling of part batches independently on machining centers M2-M5. The schedule for each of such machines consists of a sequence of part batches intermixed with idle periods taking into account tool changes in consequence of either a wearing or a batch change. Interactions neglected in this phase will be stressed by the plant simulator so that modifications con be made to previous schedules, thus giving rise to an iterative process of scheduling-verification until a satisfactory solution is achieved.

Individual schedules on machining centers are built according to the following considerations.

In order to minimize the total number of fixtures it is convenient for each batch of parts to be worked at the same time by the minimum number of machines and for each workstation to machine two or three batches concurrently. The first assumption also reduces duplications of tools. The last statement means that if batches of parts i and j are to be concurrently worked on the same machine, the sequence of individual parts to be machined is i,j,i,j,etc.

An important notion to be introduced now is the turn-around-time (TAT) of a part. The TAT of a part is assumed to be the minimum time required to go from the output buffer to the input buffer of the same workstation: it comprises the travelling time spent on the conveyor, washing, drying, unload, load operations and the eventual machining on the lathe M1 in the absence of any interaction with other parts. The efficient scheduling of part batches to be concurrently worked on a workstation depends on their turn-around-times; also the instant at which a machined part con leave a workstation output buffer and return to the conveyor depends on TATs of the other part types being machined by that workstation. In fact if two part types are concurrently worked on the same machine, then a necessary condition so that the machine has no idle time is that the TAT of one part is less than the machining time of the other. If three part types are concurrently

worked then the TAT of one part must be less than the sum of the machining times of the others. In this case it is necessary to keep the machined part, say of type i, in the machine output buffer until its TAT becomes greater than the remaining processing time of the subsequent part, say of type j, otherwise a new part of type i could arrive again at that workstation when its input buffer is still occupied.

By applying the above considerations an interactive program is being built: it accepts for each machining center an incomplete proposal consisting only of sequences of part batches and provides full schedules containing idle periods for tool change together with informations on the utilization of workstations.

Once schedules have been determined, the supervisor starts the simulation and controls and feeds the plant simulator that collects statistics on the plant activity.

CONCLUSION

This paper has presented the discrete event simulation package DESFOR supporting the process view of simulation. An application concerning the scheduling of a flexible manufacturing system has been illustrated and a heuristic approach making great use of the plant simulation model for the verification of scheduling decisions has been discussed. So far the analysis of the plant has been done in a deterministic environment, so future work will investigate system reactions to stochastic disturbing factors such as machine failures, variations in working times and so on.

ACKNOWLEDGEMENTS

This work is supported by the National Research Council of Italy as a part of "Progetto Finalizzato Informatica, Obiettivo MODIC". The authors wish to thank COMAU for the proposed application and especially Dr. F. Ciaffi and Ing. Pascoli for their support to the development of the plant model. Particular thanks go also to the student V. Minero for the implementation effort.

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AUTOMATION IN PERSPECTIVE--AN OVERVIEW

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INTRODUCTION

American industrial power, economic wealth, and overall well-being are generally attributed to the coupling of existing "know how" and the drive of free enterprise incentives. Productivity and economic growth without which this power, wealth and well-being seem impossible, depend in turn on existing technology. The importance of technology and of technological change has been well documented in terms of perceived effects both positive and negative in nature. The work of Kuznets (1953) provides an excellent example of such documentation: ". . . . in every industry there comes a time when the basic technical conditions have been introduced, a fundamental change has taken place, and a new era may be said to have begun. In manufacturing it is frequently the period when the machine process has supplanted labor to a substantial extent. . . ." The change from manual to mechanized and from mechanized to automated production systems is a natural consequence of our progression from a preindustrial and then post-industrial or "information" society. Work place rationalization, now the domain of computer based information processing and computer controlled operations, may involve office automation as well as various aspects of automated manufacturing to include the automated ("unmanned") factory. Productivity, be it in terms of the individual worker, an industry or the nation at large, is an important concomitant factor now as in the past. Naturally the rhetoric used to address questions concerning productivity and automation reflects existing biases as well as real or imagined dangers and fears about the future.

What follows is intended (i) as a summary reference to selected aspects of technological change and automation - their impact on manufacturing in the Untied States, and (ii) as an overview of the machine tool industry. This combination provides the perspective and frame of reference for a qualitative model of "synergy at work" in the process of progress and transformation from pre-industrial to industrial and then post-industrial society. The model suggests the need to consider the existence of unanticipated, unidentified and possibly unmeasurable effects of "synergy." That is to say - today's discontinuity or disequilibrium may well be the result of misconception and application of erroneous evaluation or measurement criteria instead of real causes.

TECHNOLOGICAL CHANGE AND AUTOMATION

We may say that technology represents the combination of skills, knowledge and tools available at any given time for use in satisfying particular physical or psychological needs. This can mean the creation of material goods for immediate or subsequent consumption or for use as tools in the creation of other tools and/or goods. It can also involve the creation of goods and tools intended to refine, strengthen or otherwise improve human capabilities of sight, hearing, learning and memory. Technological change, technological progress, and technological advance(s) seem to be terms used more or less interchangeably in current literature in spite of the intended specific meaning. Thus, basic minimum changes in technology take the form only of variation in the application of skills, knowledge, and/or tools from one day to the next or from one geographic area to another. Technological progress is represented, for example, by any instance of (i) an increase in performance speed, (ii) ease of operation, (iii) the ability to do what was previously impossible, (iv) an improvement in quality without change in cost, (v) an increase in quantity output without loss of quality and more than the acceptable proportional increase in cost. A more direct connection between manufacturing and technological change is suggested by Weinberg (1970):

> ". . . . the most useful indicator of technological change is in terms of one of its principal results - <u>the increase in labor productivity</u>. The trend in output per man-hour is a comprehensive measure that takes account not only of the change in the stock of technological knowledge but also of factors that influence its rate of application. It reflects, therefore, investment in new plant and equipment, improved skills or workers and managers, the state of labor relations and all other tangible or intangible forces that impinge on the effective use of technology . . ."

The search for ways to increase productivity, the impetus for early mechanization, now serves as the driving force behind automation. The seminal work by the Amber brothers (1962) outlines, very simply, why this is so. Industrial automation in their words, is a blend of energy converting devices (mechanisms) and information devices (control elements). Or, equally important, the substitution of machine for human endeavor (physical and mental). The computer and developments in computer based information processing have been and continue to be integral to basic advances in automation. If, according to Crossman (1965), we consider human labor divisible into two mutually exclusive categories - physical work and information processing - "then the long range effect of automation must be the displacement of human labor entirely from the productive process." Of importance in this sense is the fact that as the volume of information being processed has increased so has our ability to handle and manipulate information more accurately, at greater speed and at continuously reduced costs.

The combination of computer and manufacturing tool began with the introduction of Numerical Control (NC) concepts, defined (Dyke, 1967) "as the automatic control of machines or operations by numbers - numerical data - punched into tape or cards in coded form or recorded on magnetic tape." NC came into being as result of post World War II defense needs and United States Air Force sponsored research at the M.I.T. Servomechanism Laboratory where the term "numerical control" was coined. A prototype NC machine built by M.I.T. in 1952 was followed in 1955 by aerospace industry use of the first commercial unit. Early NC machines were limited to "point to point" and "continuous path" machining applications for aerospace needs. Power and control features for NC machines, initially based on the electromechanical and electronic regulators of the 1940's and 1950's, changed to solid state devices and then computers during the 1957-1959 period (Kirkham, 1963). Early evaluation of potential NC use such as that articulated by Schwartz and Prenting (1966), ". . . . in a larger sense, numerical control is a concept of a total manufacturing process in which design, fabrication, testing, scheduling, and management are closely interrelated. . .", has been borne out by developments since then.

Direct coupling of machine to computer through Direct Numerical Control (DNC) provided, according to Harrington (1973), "the means for closed loop management by use of information feedback to assure proper performance." The next advance in this process, the establishment of Computer Numerical Control (CNC) through the linkage of a control computer and the production machine computer, set the stage for automation in the late 1970's. The basis for this was described by Schwartz and Prenting (1966) as the development of automatic tool changing devices which allow parts that once had to be transferred from machine to machine to be completely manufactured with a single setup when such devices

are used together with a five-axis machine. Schwartz and Prenting used the term "maching center" in reference to this device. Hutchinson's (1977) reports concerning "flexible manufacturing systems" and Aron's (1981) comments about automatic night operation of an "unattended machining system" reflect present-day reality.

MACHINE TOOL INDUSTRY

Tools and the ability to improve them or to create new ones influence the usefulness of a given technology and the possible scope of its effects on an economy. New and improved tools as well as manufacturing techniques come about because of some need (e.g. better method for handling special metals; to reduce operating costs; to increase return on investment; etc.) and our ability to satisfy such needs. Wagoner (1966) emphasized machine tool development in terms of the interrelationship between the reduction in effort and skills required to control tools and the ability to expedite high quality work. McDougall (1963), in a similar fashion, called attention to the role of machine tools in making possible mass production, parts standardization, and precision manufacturing. McDougall also referred to the link between machine tool and an existing need: ". . . the data that have been assembled suggest that the demand for light, metal-cutting machine tools was relatively small during the initial period of industrialization when technical development was embodied in fairly large and crude systems . . . ."

In general practice the term "machine tool" is used to refer to all metal cutting, metal forming, and other metal working equipment regardless of accuracy as to specific meaning. The formal classification of "metal working machinery and equipment," in use by industry and government alike under the Standard Industrial Classification (SIC) 354, covers five separate sub-categories pertinent to this paper:

(i) Metalcutting Machine Tools - SIC 3541
(ii) Metalforming Machine Tools - SIC 3542
(iii) Special Dies and Tools, Die Sets, Jigs and Fixtures - SIC 3544
(iv) Machine Tool Accessories and Measuring Devices - SIC 3545
(v) Metal working Machinery, except Machine Tools - SIC 3548

Consumer demand affects production and, in turn, industry demand for machine tools to satisfy production needs - establishing thereby the more or less unstable nature of the machine tool industry. As a result - changes in technology and technological improvements are simultaneously sought as well as, if possible, avoided. This is a well recognized situation and often alluded to in language similar to that used by researchers at Scudder, Stevens and Clark (1970):

> . . . .Machine tools have often been called the master tools of industry. They are largely used to make other tools and many forms of capital goods. The demand for machine tools is, therefore, not a direct one. It depends on the demand for capital goods which, in turn, depends on consumer and government demands. Whereas the demand for capital goods is more volatile than the demand for consumer goods, the demand for machine tools is more volatile than that for capital goods. . . .

The growth of other industries, even if short-lived, normally provided the incentives for major changes in and improvements to the tools provided by the machine tool industry. The automotive industry assumed the role of driver early-on with, obviously, positive results even before the introduction of the moving assembly line in 1913. The development of centerless grinding in 1921 (Woodburry, 1958) and the use of splitting and straddle-milling operations on crankshafts as early as 1910 (Wagoner) are but two examples of automotive influence. Concurrent improvements permitting the use of a single operator to tend several machines at the same time did not guarantee problem free operations for the industry as we learned from Wagoner:

> . . . . Machine tool users demanded that new tools be a great deal better than the tools they replaced before they would agree to purchase new equipment. Automobile manufacturers, for example, frequently specified that new tools must pay for themselves within one year and explained this position by referring to the fact that changes were made in the product each year which might make the machine tools obsolete. . . .

The aerospace and electronic industries, separately as well as collectively, provided the impetus for post World War II advances in machine tools. Basic improvements in machine durability, tool cutting performance and power capability preceded the introduction of numerically controlled machines. Electro-discharge machining and electro-chemical machining are but two of the special processes developed for handling special metals, alloys and composite materials. The potential of these techniques, as emphasized by Smith (1968) lies in refined power supplies and better electrodes and dielectrics which make it possible to control metal removal from more than 100 cubic inches an hour to as little as 0.001 cubic inch an hour. The laser, first used in 1965 in a Western Electric mass production situation for boring holes in diamond dies (Kestenbaum, 1972), is thought (Longfellow, 1972) to have been used to its fullest advantage in micro-machining - particularly for thin film and semiconductor circuit processing. Industrial robots (or manipulators), having little outward similarity to the robots of science fiction or the robots

envisaged by the social critic concerned about the "dehumanizing aspects" of the modern workplace, are among the most recent developments in machine tools. Kurlat and Gonsalves (1970) provide a useful definition:

> . . . . we consider a robot to be any system which integrates decision-making and mechanical operations into a functionally self-contained unit, and consists of the following three components: (1) sensors capable of providing input data in a define environment, (2) artificial intelligence (AI) including a computer and communication network which gives the robot the capability to learn and to modify responses, and (3) Effectors capable of performing physical operations that modify the environment . . ."

Table 1. Machine tools--overview

(A) Machine Tools in Use -- Age Composition

Year	Number Units	<10 Years	10-20 Years	>20 Years
1973	3022791	41.8%	37.7%	20.5%
1978	⊖ 2630700	⊖ 39.6%	⊖ 35.0%	⊕ 25.4%

(B) NC Machine Tools - Distribution by Industry

Metalworking Industry	1968 Number	1968 %	1973 Number	1973 %	1978 Number	1978 %
Metal Furniture and Fixtures - SIC 25	Not Available		33	0.1%	100	0.2%
Primary Metals Industries - SIC 33	121	1.0%	379	1.3%	750	1.4%
Fabricated Metal Products - SIC 34	960	7.7%	2535	8.8%	5800	10.8%
Machinery, Except Electrical - SIC 35	6070	48.5%	15255	53.2%	30000	55.7%
Electrical Machinery and Equipment - SIC 36	1985	15.9%	3744	13.1%	4950	9.2%
Transportation Equipment - SIC 37	2911	23.3%	5108	17.8%	9350	17.3%
Precision Instruments - SIC 38	278	2.2%	1334	4.7%	2500	4.6%
Miscellaneous Manufacturing Industries - SIC 39	192	1.5%	268	0.9%	450	0.8%

DATA: U.S. Government. Employment and Training Report of the President (including reports by the U.S. Dept of Labor and the U.S. Dept. of HEW, transmitted to the Congress 1980) Washington, D.C.: United States Government, 1980, Table C-4, p310;"11th American Machinist Inventory of Metalworking Equipment 1973," American Machinest, October 1973; "12th American Machinist Inventory of Metalworking Equipment, 1976-78," American Machinist, December 1978--various pates; U.S. Government, Fifteen Years of Numerically Controlled Machine Tools, 1954-68. U.S. Dept. of Commerce, Washington, D.C.: 1968, Table 7.

In spite of major accomplishments and contributions to socio-economic progress over the years, the machine tool industry has never been large when compared to other industries in terms of numbers of people employed, number of firms, or gross sales. As reported, for example, by the National Machine Tool Builder's Association (1977) - the industry employed 75,366 persons, or 0.0833 percent of durable goods sector employment, in 1958 and 16,600 persons, or 0.696 percent of durable goods employment in 1972.

The number, type and age of machine tools in use at any given time as well as their distribution among metalworking industries are, if nothing else, indicative of technological change dynamics. Instability of demand over the long term and the issue of actual or perceived equipment obsolescense are pertinent factors. The momentum of techonological change is another, perhaps key, consideration Some of these dynamics are reflected in Table 1.

The number of NC machine tools in use by these industries increased, as would be expected, during the period 1968 to 1973 and 1973 to 1978 as well. The distribution of NC tools from industry to industry, however, remained more or less unchanged in relative terms. The absolute number of all categories of machine tools in use by these industries dropped 13 percent, or 392,091 units, during the 1973 to 1978 period. This drop affected each industry. Changes in the age composition of these tools is also reflected. A decrease in the relative number of tools under ten years of age and between ten and 20 years in age but an increase in the number over 20 years in age.

SUGGESTED MODEL

The Setting

"Synergy" or "synergism," so well articulated by R. Buckminstier Fuller (1975) may be defined as the concept that "the whole is greater than the sum of its parts" or, in even simpler terms, as "doing more with less." Recognition of the existence of "synergy" in this sense seems implicit in the literature dealing with problems concerning socio-technical systems or with questions about technological change and technological progress. It, however, also seems to be recognition in the sense of "a given" without elaboration or reference to any need for explanation or discussion. When explicitly alluded to--"synergy" appears to be associated with learning curve applications, economies of scale, cost reductions and similar situations.

The need to understand, control and explain ongoing phenomena such as automation motivates study and research but in a mode

TABLE 2

Machine Tool User Industry Profile -- Machine Tools and Production Workers

Metalworking Industry	MT Units	As % Of Total	Pr. Wk. % Total	PW/MT Ratio	MT Units	As % Of Total	Pr. Wk. % Total	PW/MT Ratio
Metal Furniture & Fixtures SIC 25	43666	1.4%	5.6%	6.2:1	36800	1.4%	5.3%	8.1:1
Primary Metals Industries SIC 33	162876	5.4%	13.5%	9.6:1	117300	4.4%	12.6%	1.1:1
Fabricated Metal Products SIC 34	638405	21.1%	17.0%	2:1	631600	24.0%	16.7%	2:1
Machinery, Except Electrical SIC 35	1103568	36.5%	18.7%	1.3:1	961000	36.5%	20.1%	1.6:1
Electrical Machinery & Equipment - SIC 36	398665	13.2%	17.9%	3.4:1	339100	12.9%	17.3%	3.9:1
Transportation Equipment SIC 37	400911	13.3%	17.8%	3.3:1	361100	13.7%	18.1%	3.8:1
Precision Instruments SIC 38	164290	5.4%	4.6%	2.1:1	132500	5.0%	5.3%	3:1
Miscellaneous Manufacturing Industries - SIC 39	110410	3.7%	4.8%	3.2:1	51300	2.0%	4.6%	6.8:1

DATA: U.S. Government Employment and Training Report of the President (Including reports by the U.S. Department of Labor and the U.S. Department of Health, Education and Welfare, transmitted to the Congress 1980), Washington, D.C.: United States Government, 1980, Table C-4, p310; "11th American Machinist Inventory of Metalworking Equipment, 1973," American Machinist, October 1973; "12th American Machinist Inventory of Metalworking Equipment, 1976-78," American Machinist, December 1978--various pages; U.S. Government, Fifteen Years of Numerically Controlled Machine Tools, 1954-1968. U.S. Department of Commerce, Washington, D.C.: 1968; Table 7.

apparently more restrictive than would be generated by addressing "synergy," in all of its various ramifications, as the possible underlying process. Linear instead of dynamic approaches are used and first instead of higher order effects are identified. Naturally the answers sought as well as the answers obtained are to questions appropriate (and therefore limited) for the investigator's special field of interest, expertise, and/or the perceived nature of the given problem. The search for causal relationships is, as always, multi-faceted and integral to such study.

Profit, considered the strongest of free enterprise incentives, serves as both impetus and constraint to technological progress. Impetus--whenever the expected returns are high, or even when not so high but assured for some period of time; constraint--when the investment required and known risks are too high or the expected rate of return is too low to compete with other opportunities. This dichotomy provides the setting for the ongoing "arms length" adversary relationship between two of the three traditional factors of production--capital and labor. A key element in this relationship is the question of how to increase productivity (e.g., the quantity of goods and services provided per unit of labor) in view of high but increasing costs of labor. Gold (1975) called attention to the major problem in this area--allowing an increase in wages to offset benefits from innovations brought about through increased expenditures for equipment and facilities. Major aspects of the industrial production question--particularly input, transformation, and output--are commonly addressed through the application of a variety of quantitative mathematical models. Recent approaches to productivity questions may be considered qualitative as well as revolutionary: Benoit (1976) identifies the need for an economy in "dynamic equilibrium" with concomitant reduction of output and consumption; Daly's (1976) "steady-state-economy" is maintained through a balance of "marginal costs with marginal benefits;" and, the "zero economic growth" economy suggested by Thurow (1976) requiring "zero population growth" and the use of productivity to establish overall limits to growth.

Labor, the human factor of production, is the focus of attention in regard to education level, skills possessed and, in those situations directly affected by automation, retraining or up-grading needed to cope with new requirements. The possibility that technological advances in the automation category permit increased use of less skilled labor has been suggested but, apparently, not seriously studied. The idea of "human capital," a recent manifestation of the attention given labor, is thought by Kreps and Clark (1975) to reflect the importance attached to education and training by everyone in the work force. This importance was attributed to expectations of greater productivity and the ability to directly profit from it. Economic manpower questions,

addressed at the same time by Kreps and Clark, point to the overall "utility" of some formal measure of education and/or knowledge levels. The essential role of education in improving the quality of labor or simply creating "better labor" was emphasized by Machlup (1970). Education seems to have negative aspects as well; as can be noted from an Ad Hoc ASEE Committee (1977) monograph:

> . . . .the concept of 'fewer and better' students entering engineering might be a very healthy one, considering the great progress being made in the supporting tools used by the engineer. An oversupply of engineers may have led to their being employed at sub-professional levels. . ."

Research and development, part of the formal process linking science and technology for society, are thought to have singificant effects on the present and future alike. Basic and applied research, the pursuit of the theoretical on the one hand and the practical on the other, identify new opportunities for technological changes and improvements in existing products or technologies. The means for solving problems or for moving closer to possible solutions are created thereby. Rosenberg's (1976) comments that "the technological realm is 'self-contained' in that it generates knowledge as a by-product of the productive process and then exploits such knowledge itself in the same process" are pertinent in this sense. At the same time Rosenberg calls attention to inter-industry technological flow which has brought product as well as process improvements to given industries in spite of minimum research and development expenditures on their part.

Information, another key link between the various components of technology, only recently acquired significance as a resource having properties not associated with other resources. McHale (1972) considered these properties unique due to (i) the dependence of other resources on information and (ii) the fact that with more use information tends to increase, instead of decrease, in value, size, and importance. The immediacy and impact of information grow in importance through communication, an essential ingredient for the diffusion of technology. As technology changes so does communication--in terms of, (i) the variety, speed, effectiveness and lower cost of available equipment, (ii) the skills and education required to operate such equipment, and (iii) the flexibility, scope and complexity of available techniques. The cycle is complete and the loop closed--a change takes place; information about it is gathered and then communicated; as diffusion takes place other changes take place, there is feedback, etc., in non-stop fasion. Granted that perpetual motion machines of the first and second kind cannot exist in the physical world, the "more for less" result in interaction between information, technological change, knowledge, invention and innovation in an

unending fashion seems to be in the category of something more than an illusion for the "soft" sciences."

Changes in occupational structure, functions, as well as processes, within the manufacturing sector are suggested by present day technology. The overall reduction in machine tools on hand together with changes in age composition as reflected in Table 1 support this view. Limited analysis of 24 manufacturing industries (in both, durable and nondurable categories) in regard to workforce composition by production and non-production elements is possible on the basis of Table 3. Shown therein are the changes in manufacturing sector employment in relative numbers per 100,000 members of the civilian labor force during the period from 1944 to 1977. Of interest is the overall drop in production workers and the indication that only two of the 24 industries added production workers to their rolls.

"Synergy" At Work

The interrelatedness and combination of technology, research and development, machine tools, education, information, etc., imply the existence of a cybernetic structure within the given social system. This structure serves as a "black box" mechanism--permitting observation and study of a variety of components in search for system understanding. Because of available knowledge, tradition conditioned methodology and expectations--observed input and output are identified, the transformation process, although unobserved and not understood, is nevertheless measured over time. As input, transformation and output are correlated, the input/output relationship is established and we are able to note (particularly under the influence of "synergy") that "productivity has increased or decreased, that quality of output changes with changes in input mix, etc." Since the structure is a "black box" the complexities of internal procedures (feedback, component relationships, their actions and reactions) and possible ramifications are neither observable nor observed. We expect input X to result in output Y and consider all instances of this as acceptable events; what we do not realize, however, is that possibly output Z also occurred, that input X is really equivalent to 2X and that system changes responsible for these new conditions took place a long time ago. The workings of the underlying process are unanticipated in such a situation and when finally recognized to some degree may not be measureable.

A new approach to the "black box" is needed--one that will re-calibrate, so to speak, our investigative mechanisms and at the same time improve our observational capacities. Disregarding for the moment the difficulties involved in providing the quantitative basis for this approach permits focus on the qualitative aspects.

TABLE 3. WORK FORCE COMPOSITION - MANUFACTURING SECTOR CHANGES 1947 TO 1977

Industry	% Change 1947 to 1977	Industry Employment Changes per 100,000 Members of Civilian Labor Force: Total	From 1947 to 1977: Prod.	From 1947 to 1977: Non-Pd.	Production Workers as % Total WF in Each Industry: 1947	1977
Durable Goods						
Ordnance & Accessories	+253.3%	159	+ 35	+ 79	81.5%	45.5%
Electric Equip. & Supp.	+ 13.9	1987	- 44	+ 287	81.5	77.8
Aircraft & Parts	+ 22.1	492	- 48	+ 139	74.1	50.9
Instruments & Related	+ 20.2	541	- 28	+ 119	79.8	61.2
Furniture & Fixtures	- 7.4	524	- 69	+ 27	88.1	82.2
Stone, Clay & Glass	- 26.0	670	- 261	+ 26	87.7	79.6
Fabricated Metal	- 10.6	1490	- 262	+ 86	83.5	75.8
Other Primary Metal	- 35.5	677	- 376	+ 3	86.5	78.5
Machnry., Ex. Electric	- 3.1	2245	- 374	+ 302	79.1	65.0
Other Trnsptn. Eq.	- 2.9	439	- 51	+ 38	88.1	78.9
Misc. Manufacturing	- 39.4	430	- 290	+ 21	87.2	76.2
Lumber & Wood Products	- 53.7	659	- 758	- 7	92.7	85.1
Blast Furnace & Steel	- 49.6	559	- 534	- 16	87.7	77.9
Motor Vehicles & Eq.	- 29.4	914	- 344	- 36	81.5	77.8
Nondurable Goods						
Rubber & Plastics (Nec)	+ 27.4	693	+ 100	+ 49	81.4	78.4
Apparel & Other Textls.	- 31.9	1323	- 630	+ 9	90.7	85.7
Paper & Allied Prods.	- 8.3	718	- 145	+ 80	87.3	75.1
Printing & Publishing	- 6.3	1139	- 164	+ 88	67.5	57.6
Chemicals & Allied Pr.	- 0.7	1086	- 199	+ 191	75.2	57.4
Tobacco Manufactures	- 63.8	72	- 127	0	93.2	87.2
Food & Kindred Prods.	- 41.7	1766	-1153	- 112	77.5	67.8
Textile Mill Products	- 54.0	1088	-1177	- 4	93.9	87.2
Petroleum & Coal Pr.	- 42.2	215	- 145	- 12	76.9	66.5
Leather & Leather Pr.	- 61.0	271	- 398	- 25	90.8	85.5
		Totals			Average	
		20157	-7442	+1332	88.8%	72.6%

NB 1947 civilian labor force fiture is that for persons 16 years of age and over. 1977 civilian labor force figure is preliminary.

Data: Economic Report of the President (transmitted to the Congress January 1978 together with the Annual Report of the Council of Economic Advisers), Washington, D.C.: United States Government, 1978, Table B-27, p. 288; and, Employment and Training Report of the President (including reports by the U. S. Department of Labor and the U. S. Department of Health, Education, and Welfare), Washington, D.C.: United States Government, Tables C-4, C-5, C-6 & C-7, pp. 267-27.

The suggested framework for dealing with these aspects and for formalizing their proper relationships is outlined below in very general form.

(i) Research and development -- from invention to innovation in terms of both product and process.

(ii) Machine tools -- developments concerning regular and special applications, operating characteristics, census of tools in place and pertinent facts.

(iii) Education and knowledge -- from the standpoint of lower and upper boundaries/constraints, on-going growth, significance to specific industry activities and the process of technological change.

(iv) Production element of the manufacturing sector work force -- status by number, skills required, scope of work.

(v) Investment in plant and equipment -- according to inter and intra-industry composition.

(vi) Information -- as the mechanism linking all aspects of this system and as a possible surrogate driver (for the human controller) of key system components.

Some kind of index or metric for purposes of identifying as well as measuring observed system conditions may be required if suggested problems are to be avoided. It is also clear that to some degree, simulation of pertinent system variables may provide the only means for determining model feasibility, validity, and usefulness.

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INTEGRATION AND THE DEFINITION OF RESPONSIBILITIES

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INTRODUCTION

This paper addresses the problem of providing adequate guidelines for those concerned with introducing, modifying or designing management information systems, particularly in small manufacturing industry. It is an important subject in view of the potential for using computers and the point that because they have prime access to the technology there will be a tendency for systems to be inspired more by technologists than by the managers and people who use them. Since technologists are generally uncomfortable with the subjective, less well defined subjects of the humanities and are more excited by the technical means of handling information than by its use or the human factors that surround it, there is a need to:-

(a) improve our understanding of an increasingly important subject so that we can exploit the new opportunities technology can provide, and

(b) project this understanding in a manner which is of practical use to those concerned.

Here, the company is examined using the systems approach with control as the principal theme. The paper is in three sections. The first is theoretical and concerned with the definition of integration, the system elements and the relevance of control. Section 2 uses the theory to produce a checklist of points for the system designer and to outline the methodology. Section 3 provides a practical example in support of the theory.

SECTION 1 INTEGRATION AND CONTROL

The integration of any set of activities infers that each acknowledges the existence of the others, a point which must be recognised by those responsible for both the individual activities and the complete set. Companies represent one kind of activity and the extent to which this is divided into sub-activities will depend on the size, nature and state of development of the particular company. Woodward[1], and Burns and Stalker[2] have identified various forms of organisation and Fig. 1 shows a grid against which it is possible to classify any company. It illustrates that in any organisation there is a balance between the extent to which authority and responsibility are subdivided and the extent to which it is thence desirable to formalise internal communications. The four points and arrows show the hypothetical development of a company.

(A) The owner-director type of small business or entrepreneurial company in which decisions and responsibility are in the charge of one man. There is no formal organisation with the people having multiple roles and tasks in a relatively homogeneous group.

(B) The company is now too large for one man to manage and has thus divided responsibilities. Relationships are still largely informal. It is essentially a development stage and depends on the ability of the individuals managing it to recognise the boundaries of their authority and to pull together.

(C) This is a development of B whereby the activities and responsibilities are clearly defined and more formal systems of communication and decision making are in evidence.

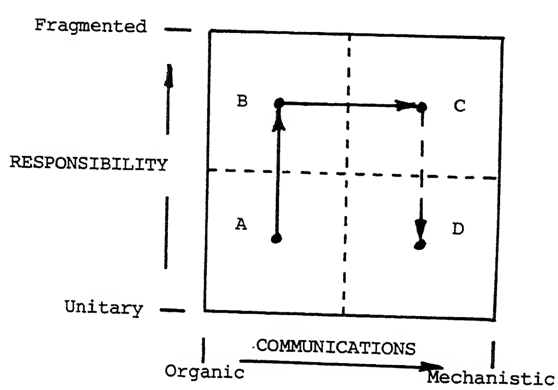

Fig. 1. Forms of Organisation

(D) A theoretical rather than practical case, in which the formal organisation of subactivities is sufficiently well defined for the company to respond to direction from a single source "at the top". A fully automated chemical plant can be operated by one person. In theory this approach could be extended to systems which include people and there will be a greater tendency to attempt this as automation and computer supported information systems extend their influence.

The latter represents a popular view of a fully integrated system. In practice it is unlikely to work successfully for reasons which are herein discussed. This paper is concerned with "integration" as it affects the operation of companies like B and C, in which the delegation of responsibility and authority are retained and the setting and achieving of a coherent set of objectives are the main issues.

The subdivision of activity and responsibility, because of problems of scale and the subsequent need to integrate the subactivities, almost invites a systems treatment. However, instead of using "decisions" or "individual actions" as the basic elements of a manufacturing system, the proposition here is to take control, with its four elements (aim, plan, action and feedback), as the basic building block. The smallest block is the individual, either as himself or, where appropriate, as a manager. These individual building blocks go together towards making the company itself. We can extend Argenti's[3] control model of the manager (Fig. 2) to the individual (Fig. 3) by bringing in the influence of personal goals in addition to those of the company. In Fig. 3 the individual, in planning how to carry out a task will, implicitly or explicitly, take into account such matters as the chance of him being able to do the task (skills), the likelihood that performing the task will meet his personal goals (wage payments, job satisfaction and other aims), and the aims of the company. These factors together, which are essentially the expectations approach[4], should determine the level of the individual's motivation to perform the task and the level at which he performs (his action). The checking of his performance against his aims provides the individual with feedback to adjust his plan where necessary.

The simplified control model of the company, shown in Fig. 4[5,6] is generalisable for many activities but is shown here for just two activities, SALES and PRODUCTION. For simplicity also, only the operational level is shown, with the strategic and tactical levels being ignored. Notice that control of both the SALES and PRODUCTION activities comprises the four elements that we have identified.

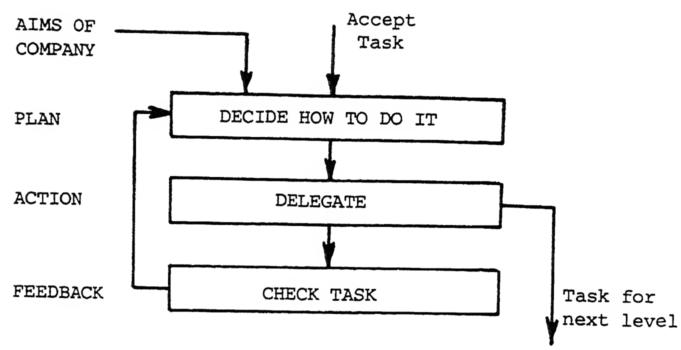

Fig. 2. Control Model of a Manager

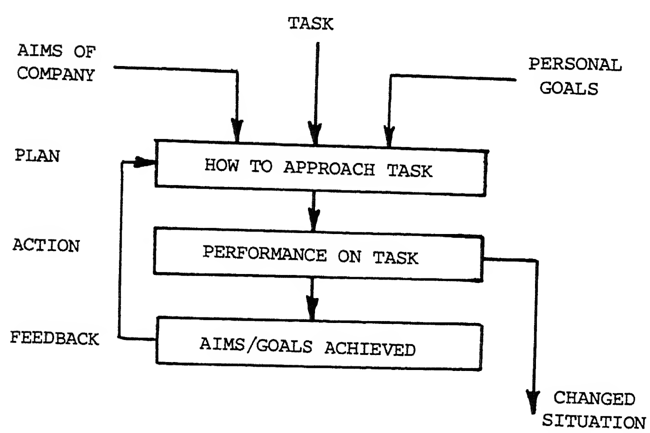

Fig. 3. Control Model of an Individual

Note also that in each case feedback is present for several purposes:

(i) the check by whoever set it, that the TASK was performed.

(ii) the check by whoever set the task that THEIR AIMS were being advanced (or not).

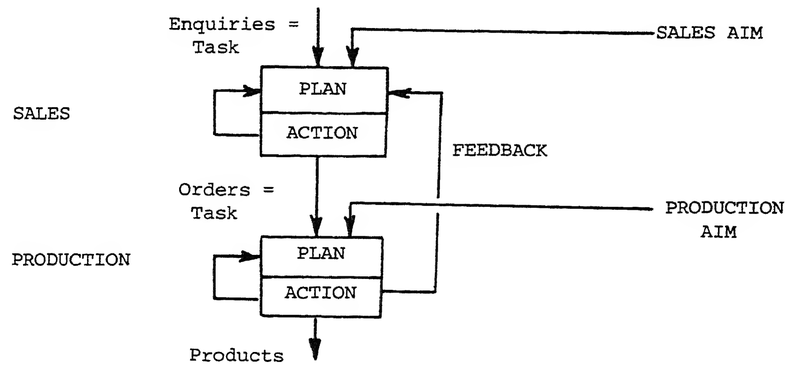

Fig. 4. Example of Company Model

(iii) the check by those doing the TASK that it was performed and their LOCAL AIMS were being advanced (or not).

The distinction between an AIM and a TASK is important, particularly in relation to human goals. In a company the aim may be to achieve sales revenue of £1,000,000. This is not the same as the task of selling. A cabinet maker may have the task of making furniture which is not the same as the aim of being a master craftsman.

The concept of control infers that aims are not likely to be achieved automatically - various factors have to be manipulated. In any company, management control involves the coordination of the various tasks being undertaken. The way in which this is done and the degree of success achieved will be influenced by such things as, variations and disturbances in the environment around the individual and the company, the size, ownership and technology of the company and the behaviour of individuals[7]. The contingencies of environment, size, ownership and technology will affect the way in which the control building blocks of the company are organised. The behaviour of individuals will be influenced by the way in which their own goals agree or conflict with those of the company and in turn affects their expectations. The control system will be constrained to the extent that control cannot be exercised over an environment which demands action beyond the limits of the system and to the extent that the skills and motivation of individuals constrain their ability to plan and act.

The criticisms of automatic control-type models are that systems which include people are too highly adaptive and their

aims too difficult to discern. This is really an admission that we are unable to quantify critically important parameters rather than a criticism of the model. In the absence of these parameters any approach is, of course, limited. We are here concerned with the simplest expression of the interaction of parameters. This alerts us to their influence and acts as a checklist of the items to take account of in any particular case.

For example, a company, its managers and its employees must exist in the population at large. There are two systems of direct interest, the "company" and the "system of people". They coexist, with the latter having indeterminate boundaries because the non-employees in the population influence the employees. The systems, almost by definition, are in a dynamic state of balance whereby all the individuals are striving to achieve or have achieved their aims (public, company and personal), through their plans, their actions and their contribution to the plans and actions of others (company and public). They do this within the current ambience of attitudes, constraints on resources and limitations of skill. Why the company is performing as it does can be explained. However, the "problem" is more usually posed as: "Why is it NOT PERFORMING in some other way?". Again the theory helps us. To perform in a particular way there are pre-requisites, the determination of which spring directly from the model and form the basis for the methodology in the next section.

SECTION 2 METHODOLOGY

The methodology is directed towards the system designer or innovator. It assumes that a preliminary study has been carried out and that those involved are familiar with the existing activities and organisation. The steps are thence as follows:-

Step 1

Why is innovation to be considered? In regard to Fig. 3 is this to satisfy some personal goal of the person suggesting it, is it to satisfy some identifiable aim for the company, or is it a mixture of the two? If it is largely for the individual there may be reservations as to the amount of motivation that can be raised in the rest of the company in support of the intended change.

Step 2

Is the suggested innovation relevant and valid? Is there some better, other innovation or change which is relevant and valid? If so, is it compatible with the aims (company and personal) of those responsible for agreeing to it? If not, it is futile to proceed.

The second step is a demanding one and requires analysis and the exercise of judgement. Proceed as follows:

2(i) What are the principal subdivisions of responsibility in the company, e.g. sites, divisions, sections, departments, functions?

2(ii) Are these subdivisions consistent with the subdivision of physical activity, e.g. do Sales actually have authority over selling?

2(iii) Are the sub-areas of responsibility (activity) controllable, e.g. are they of such a size that they can be led towards a specified objective? The factors affecting this are the numbers of people involved, the quality of leadership, the incentive to pursue company aims particularly in relation to their compatibility with personal goals and company aims. If the sub-areas are not controllable, then further subdivisions of activity, changes of leadership, modifications to incentives etc must be considered.

2(iv) Are the aims of a given sub-area consistent with the company's overall aim and with the aims of other sub-areas? Are the aims specified in terms which are of practical use in planning that activity and utilising feedback? For example the aims, "do your best" and "increase output" are perhaps worthy but inadequate. They have unknown implications for other sub-areas (particularly at operations levels) and weaken their plans and actions.

2(v) Does the control information receive support from the management information system? Do policies exist in relation to operations and the allocation of resources? The one affects the external performance to customers and from suppliers, the other affects internal performance[5]. To be supportive some quantifying of policy should be evident in the information system. Examples might be recommended levels of stocks and work-in-progress, lead times, mix and manning.

2(vi) Do procedures exist at the operational level to ensure that control information has (reasonable) integrity?

2(vii) Do the senior managers recognise their responsibilities towards the control system, e.g. towards the other sub-areas of responsibility and do they appreciate that there is a company aim as well as sub-area aims and personal goals?

Upon reaching 2(vii) one should have a clear idea of the <u>fundamental</u> issues, of why the company is performing as it does and whether it can be controlled to achieve any other kind of objective. The steps are consistent with the control concept:-

1.	Start with the	AIM
2.	Proceed to	PLAN
3.	Then carry out	ACTIONS
4.	Is the aim being advanced	FEEDBACK

Unfortunately the WHY is not usually directly observable. It is the ACTION (or WHAT), as indicated in the physical activity, followed by the PLAN (or HOW) as expressed in the details of the organisation and procedures, which are prominent in reality and thus most easily examined. Their investigation is also a significant portion of any analysis and innovation must eventually cause changes at this level. Their priority is, however, not as fundamental as that of resolving and reconciling aims. The following practical technique for examining a company epitomises this distinction.

Step 3

3(i) Examine the organisation from the top, following the delegation of authority (responsibility) as defined by the previous higher level and test each sub-area as expressed in Step 2. This is an AIM oriented, fundamental approach.

3(ii) Examine the tasks which the company performs at the operational level; market forecast through sales to production, invoicing and despatch for example. What evidence is there, looking "upwards" into the organisation, that actions are influenced by plans and a recognition of company aims? What evidence is there that sub-areas are pulling towards a coherent set of aims? This is an activity oriented pragmatic approach, which is necessary but inclined to lose impetus in the mass of detail, the purpose of which may not be properly perceived because it relates to large numbers of people and includes their attempts to achieve personal goals as well as their contributions to company activity.

In practice either method may be used to illicit information and a combination is very often a workable compromise.

(Stages of proposal, discussion, specification, design, test and implementation would normally follow[5]. These stages raise issues about good practice but, in this context, few points of principle. They are omitted to avoid obscuring the fundamentals.)

SECTION 3 AN EXAMPLE CASE

This case concerns the real company shown schematically in Fig. 5. Metal is melted at a Central Facility and distributed to two casting plants, A and B, at a distance of 3 kilometres. It is transported in large ladles on bogeys, pulled by general

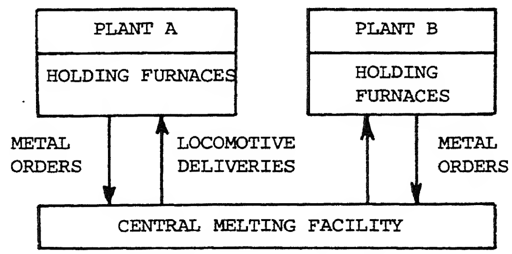

Fig. 5. Coordination of Metal Movement

purpose locomotives. At the Central Facility scrap metal is melted in a furnace, mixed with additives in a special ladle and then transferred to the transport ladles by crane. The time taken to provide a ladle from receipt of a request is approximately one hour provided there is a regular demand on the furnace. The locomotives take the ladles to the casting plants where metal is poured into electric holding furnaces. From these the metal is drawn for casting as required. Each transport ladle contains twice the capacity of the holding furnaces and stands until both the "first" and "second" pours have emptied it.

The problem was that the casting plants were running out of metal thereby causing several hundred men and expensive plant to stand idle. This was quite aside from time lost due to technical faults and disputes. The reasons were thought to be in "the running of the Central Facility and Casting Plants". A number of consultants had investigated the situation and there were broadly two kinds of suggested solution. One concentrated on gathering information about everything and the development of an algorithm for instructing those involved about what actions to follow all the time. The other type left the decisions of what to do with those involved and concentrated on clarifying their aims. Proposals of the first type were rejected. A proposal of the second type was accepted and implemented because, among the other reasons they considered that "it helped them to do their job". The innovations followed the methodology already discussed, with the following answers to the questions posed being obtained:-

Step 1. There was a clear reason for innovation, namely to reduce stoppages due to poor coordination.

Step 2. It was valid because the managers agreed the reason and there was clear evidence for the stoppages in works records.

Step 2(i). The subdivisions were:- Central Melting Facility, Casting Plants A and B, Holding Furnaces A and B, Locomotives.

Step 2(ii). The locomotives were transferred from being the responsibility of the transport manager to that of the Central Melting Facility Manager, because their activity was inconsistent with their responsibilities.

Step 2(iii). The size and organisation of each subdivision did not appear to pose problems. Morale and leadership were good. Aims were unclear and ill conditioned and the Melting Facility Foreman's expectations of the Casting Plant were that orders and times were suspect and to be treated with caution. There were always at least two versions of "recent history". The principal redefinitions of aims were:

The Central Melting Facility Foreman was charged with being responsible for meeting orders for metal from the Holding Furnaces at A and B, on time. The previous responsibility for ensuring they did not run out of metal was unrealistic because there were too many factors outside his knowledge and beyond his control. Their aim was to minimise the error between actual time of delivery and ordered time.

The Holding Furnace Supervisors were made responsible for the content of their furnaces unless the Melting Plant should fail to deliver. They were made responsible for ordering metal at least sixty minutes in advance of the delivery time. This caused them to improve their local communications with the Casting Shop Foremen, particularly about casting rates. Their aim was to have metal available for casting within the constraint of a 60 minute lead time on supply.

The Locomotive Foreman was made responsible for getting full ladles to the Plants on time and retrieving ladles as soon as they were emptied. This is their true function and the separation of them into another area of responsibility was for historical reasons no longer applicable.

Step 2(iv). The aims were already consistent. Sales and the Producing Plants had compatible aims. Their plans, action and feedback elements were in good order. It was possible to avoid involving other sub-areas in the resolution of the problem.

Steps 2(v) and 2(vi). Procedures at the Central Melting Facility and at the Holding Furnaces were modified. The main features were the introduction of a common clock which automatically timed orders and a display to indicate the status of current orders to the Plants and Melting Facility. The common clock provides the basis for reliable feedback.

Step 2(vii). The managers were careful to note the definitions of responsibility. The accounting system is able to assign the cost of stoppages more equitably to the Casting Plants or the Melting Facility by virtue of the common clock. Lateness of an order (Holding Furnace error) or lateness of delivery (Melting Facility error) are distinguishable and the new system is thus fairer as well as more effective. The extent of tangible benefits is a matter for analysis and being in the early stages of implementation the cost effectiveness has yet to be determined.

CONCLUSIONS

The methodology offers both diagnostic and prescriptive help to innovators and system designers. It emphasises the pursuit of the WHY to support the more usual concern with the WHAT and HOW of a system. It may also alert us to the point that systems are a natural product of their constituent parts. There may be no such thing as a bad system, merely systems which have the "wrong" objectives. These may need deflecting towards other objectives. Unless there is some well applied effort to define these other objectives, by the senior managers - for example, a company will adopt a dynamic equilibrium which simply reflects the attempts of all its members to achieve their aims and personal goals within the constraints upon them.

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PRODUCTION PLANNING IN A SMALL FIRM IN THE GLASS INDUSTRY

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ABSTRACT

Focusing on a small firm and its special problems a case from the glass industry is presented. The paper describes a computerized glass cutting procedure and a sequencing procedure for ordering the cutting patterns in an optimal way. It is also discussed how model sophistication, computer capacity and the need of simple administrative routines may cause conflicts, particularly in small firms.

INTRODUCTION

In the title the expression "a small firm" is used. By a small firm is meant a firm with 10-30 employees and very few people dealing with administration, with very few computer facilities and few or no specialists in e.g. operations research.

Furthermore it is assumed that the turnover is so small, that the firm can hardly bear the burden of a comprehensive consultancy.

This paper gives an example of the use of a simple and a little more advanced OR - method to plan the daily production. The case is taken from the glass industry in Denmark.

DESCRIPTION OF THE FIRM AND THE PRODUCTION PROCESS:

The firm produces thermopanes meeting customer specifications. The demand of each size of thermopane is very small (about 2-3) and there are many different sizes. The thermopanes are composed of two

or three rectangular pieces of glass of equal size.

The firm receives orders from customers. An order contains information about delivery week and order quantity, size, thickness and number of layers of each thermopane. Furthermore some special requirements such as colour, surface treatment, special glass quality can be specified. The bookkeeping and invoicing is done by a small computer but the weekly production planning itself was done manually.

The glass pieces are cut from raw glass sheets (stock sheets) of a given dimension. The cutting is performed in three stages. In the first operation the raw glass sheets are cut into sections (see figure 1) using guillotine cuts, i.e. each cut has to separate a sheet in two new rectangular sheets. Then each section is divided into smaller rectangular pieces again using guillotine cuts. Finally, the glass pieces may be trimmed on one side to obtain the required dimension. In order to give an impression of the size of the firm the average weekly production is listed. Approximately 250 raw glass sheets are cut into 1700 pieces some of which are trimmed. The length and width are given in millimeters and the glass pieces can without causing troubles in the production process be turned 90 degrees. The first and second cutting stage is performed by manually controlled machines and the trim is done manually.

After the cutting process the pieces are placed temporarily in a small inventory until the corresponding pieces of equal size are ready for being assembled to thermopanes. To facilitate the identification, matching, storing and administration of pieces and due to the size of storage facilities it is required that the inventory is not too big.

As mentioned earlier the production planning was done manually while the bookkeeping and invoicing was done by a small computer (storage 128 K bytes). Due to the increasing competition by the late 70tieth and due to the increasing price of raw glass sheets the owner of the firm wanted to improve the production planning i.e. decrease the waste-percentage and maybe also the production time. This should either be done using the existing computer or by buying an automatic, but expensive cutting machine containing a minicomputer for improved cutting. The owner preferred the first solution because it gave a better possibility for combining administration routines with production planning routines and because he avoided buying an expensive automatic cutting machine. Via the software firm which developed the bookkeeping and invoicing routines, a contact was established between the firm and IMSOR. The owner wanted a quick result, a simple method requiring simple data.

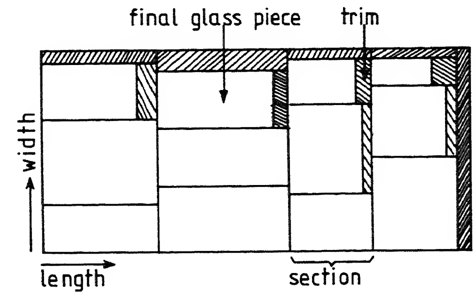

Fig. 1 Example of a cutting pattern. The hatched area is waste.

OPTIMAL CUTTING

From an ealier study (Christensen, 1975; Madsen, 1979) IMSOR had developed a computer program finding near optimal solutions to the above mentioned problem, which in OR-terms is called "a free twostage guillotine cutting problem with trim (nonexact case)" (Gilmore and Gomory, 1965). The most obvious solution to this problem is to use two-dimensional knapsackfunctions and to optimize these functions as shown in Gilmore and Gomory (1966). The difficulty is that this procedure requires too much memory in the computer and too much computertime. Recalling that the firm is small we notice that the expenses for computertime very easy can exceed the expected savings.

The procedure chosen was a near optimal double one-dimensional knapsack procedure. First the glass pieces were composed to form sections. Then the sections were put together into sheets using almost the same algorithm. The calculations were performed by a revised, ordered step-off algorithm. It was a modified version of the algorithm, mentioned in Gilmore and Gomory (1966). The modification was done in order to speed up the calculations. The results in the earlier case for a 3-day planning horizon showed a reduction of the waste-percentage from 12 to 5.

The firm decided to implement the IMSOR-system on their own computer, a Texas 990 with 128 K-bytes. The implementation was done

by the software firm which had earlier constructed the bookkeeping and invoicing routines. After 6 month experience with the cutting program the firm estimated an average reduction of the waste-percentage from 20-25 to 10-15. The computertime used for one run was 10 -12 minutes. The program has also been used for finding the best dimension of the raw glass sheets. A better dimension could reduce the waste by 3% more. The production time was also decreased in particular because it was not necessary for the workers to think so much of the cutting pattern. Figure 2 shows an example of a real cutting pattern.

After a half year of practical experience the firm wanted some minor revisions being made. Furthermore they had a major objection to the results. The firm wanted that the corresponding glasspieces forming one order should be cut within a certain time interval. In other words they required that the orders were not spread too much over the entire production run. This constraint makes the identification, matching, storing and administration of glass pieces much easier and requires a smaller inventory. The elimination of order spreading is called pattern allocation or cutting sequencing.

CUTTING SEQUENCING

The desire of keeping the glass pieces belonging to one order as close as possible gives, in fact, rise to two conflicting objectives: to minimize the waste and to minimize the order spread (the "distance" between the first and the last piece cut belonging to the same order).

In order to give a quick response to the firm a "quick and dirty" method called the horizon shrinking method was suggested. Here the planning horizon is decreased until the order spread is small enough. Experience from numerical experiments showed that the average order spread could be reduced 6.7 times and the computer time used could be reduced 5 times at the cost of increasing the waste-percentage 1.6 times. The horizon shrinking method was very easy to implement and resulted in a trade off curve between waste-percentage and average order spread.

Taking into consideration that almost no methods dealing with pattern allocation have been described in the litterature, several methods were developed and compared at IMSOR. The methods can be divided in one stage methods and two stage methods. In a one stage method both the cutting problem and the pattern allocation problem are solved at the same time. In a two stage method the cutting problem is solved first. Then in the second stage the pattern allocation problem is solved. This means that the second stage preserves the waste rate obtained in stage one.

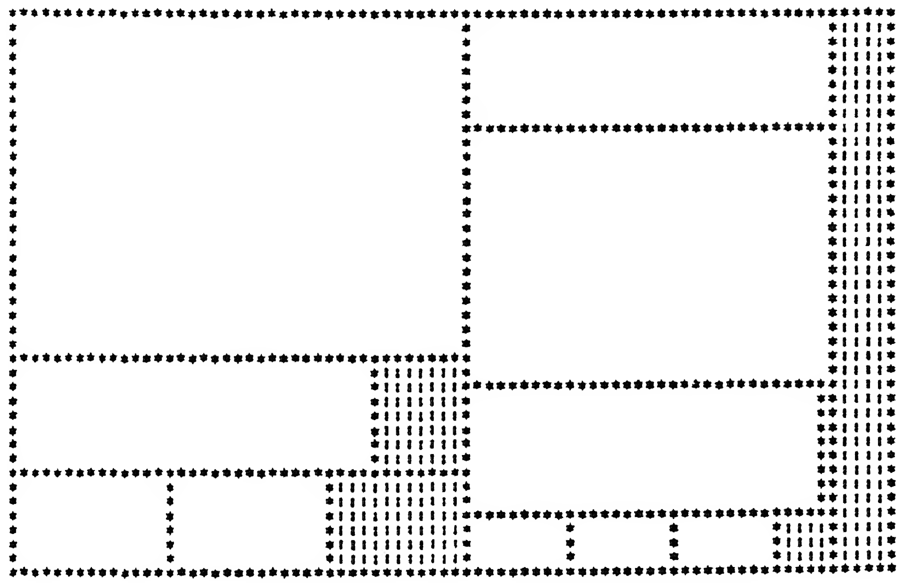

Fig. 2 Example of a real cutting pattern.

The first method mentioned, the neighbouring method, is a one stage method while the next two methods are two stage methods. The description of the last-mentioned methods will be concentrated on stage two.

The neighbouring method (TN-method)

One way to keep corresponding glass pieces together is to require that e.g. 2 corresponding pieces from a thermopane should be cut as neighbouring pieces. This can be done by defining a new piece consisting of two identical glasspieces. Taking the orientation into consideration there are 4 possibilities as shown in figure 3.

The algorithm then have only to pick out the one of the 4 alternatives which is most convenient. Of course this method can only handle cases with 2 or perhaps 3 corresponding glasspieces and not a complete order consisting of many pieces. Computational results from a 5-day period showed an increase of the waste-percentage by an average of 1.45 times. The order spread was minimal. This waste -percentage can be regarded as an upper bound for the waste-percentage while the waste-percentage resulting from the optimal cutting pattern without taking the pattern allocation into consideration can be considered as a lower bound.

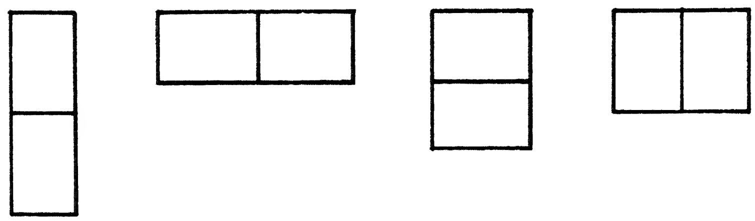

Fig. 3 The possibilities of combining two identical glasspieces.

Bandwidth reduction models

In (Madsen, 1979 and 1980) the order spreading is depicted as the bandwidth of a symmetric matrix $A = \{a_{ij}\}$ in the following way:

$a_{ij} = 1$ means that stock sheet i and stock sheet j have at least one pair of pieces belonging to the same order in common

$a_{ij} = 0$ otherwise $(i \neq j)$

$a_{ii} = 0$

It is assumed that the cutting sequence of stock sheets corresponds to the ordering of rows and columns in A, e.g. row 3 corresponds to the stock sheet which is cut as number 3 in the sequence. The interchange of two columns and of the same numbered rows will lead to another stock sheet cutting sequence, but the waste will be the same. The objective could be to exchange rows and columns in such a way so that the bandwidth $\beta(A)$ of A is minimized, where

$$\beta(A) = \max_i \beta_i(A)$$

$$\beta_i(A) = \max_{a_{ij} \neq 0 \wedge j \leq i} |i-j| \quad , \quad i=1,\dots N$$

$\beta(A)$ may be considered as a measure of the largest distance between two corresponding order-pieces. A small order spread is equivalent

to a location of all the ones in A near the main diagonal. A near optimal algorithm - The Cuthill-McKee algorithm is used to reduce the bandwidth. Computational experience from a real case indicates that the bandwidth is decreased by 63% but the average bandwidth is increased by 46%.

It can be shown that the profile of A $|P(A)|$ can be expressed as

$$|P(A)| = N + 2 \sum_{i=1}^{N} \beta_i(A)$$

The profile may be interpreted as a measure of the average order spread. Reducing the profile will lead to a smaller average bandwidth.

To minimize $|P(A)|$ a solution method is picked up from the area of finite element methods, particularly used in the civil engineering sciences. The method is called The Reverse Cuthill-McKee (RCM) algorithm. It is within a few seconds able to find an ordering that has a small but not always minimal profile.

The RCM-algorithm has been used on a 14 days production run. The standardpackage SPARSPAK from the University of Waterloo, Canada was used. It was observed that the average order spread was reduced by 28% and that the maximal order spread was reduced by 76%. In a few cases the average order spread was increased slightly but the maximal order spread was always decreased considerably. The additional computer time needed was very small compared to the time needed for stage one (6%). For further details see (Kærgård, 1981; Madsen and Kærgård, 1981a).

The travelling salesman approach

In (Madsen and Kærgård, 1981b) a travelling salesman approach (TSA) to solve the order spread reduction problem is described. Let $c = \{c_{ij}\}$ be a symmetric cost matrix where c_{ij} = k - number of orders on stock sheet i which also occurs on stock sheet j. k is a constant which is made large enough to ensure that all c_{ij} elements are nonnegative. The diagonal elements are $c_{ii} = k_1 > k$. Let $x_{ij} = 1$ if stock sheet j is cut immediately after stock sheet i and let $x_{ij}=0$ otherwise. We can now consider the order spread reduction problem as a travelling salesman problem. A dummy cutting pattern containing no orders is introduced to avoid a circular sequence connecting the last stock sheet cut with the first stock sheet cut. When the solution is found the first stock sheet to be cut will be the sheet just after the dummy sheet introduced.

One of the major objections against the above-mentioned formulation is that if the cutting of one order is stopped it does not

matter when it is started again. The weakness in the formulation may result in an increase in the order spread if the results from TSA are used.

An experimental computer code based on TSA has been implemented. The travelling salesman problem is solved by using the near optimal heuristic the 3-optimal method by Lin (1965).

The computer code was applied to the case which was mentioned in the bandwidth reduction section. The average order spread was reduced by 31% and the maximal order spread was reduced by 18%. In a few cases the order spread was increased in accordance to the above-mentioned objection to the formulation. In these few cases the original result just after stage one can be used instead. The computing times were in average 3 times larger than the computing times mentioned in the bandwidth reduction section.

A comparison of these results to the bandwidth reduction results seems to indicate that the bandwidth reduction method gives slightly better results and needs less computer time. The advantage of TSA is that the code is very short compared to the standardpackage SPARS-PAK.

General comments

In this section some methods solving the order spread reduction problem are discussed. For the time being the firm uses the horizon shrinking method. The neighbouring method can not be recommended. The bandwidth reduction method and the travelling salesman approach can both be recommended but these methods have not yet been implemented on the firms computer. Some problems still remain in particular concerning limited computer storage.

CONCLUSION

It is shown in the paper how a computerized glass cutting and sequencing procedure can be implemented in a small firm. The implementation is done step by step and it is still in process.

The advantage of small firms is a very short decision hierarchi resulting in a possibility of fast decision making. This means that e.g. results from an operations research study may be implemented very fast. On the other hand the shortage of money and administrative routines makes it difficult to use ordinary standardprocedures.

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NEED ASSESSMENT - A TOOL FOR IMPROVING MANUFACTURING SYSTEM DESIGN

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INTRODUCTION

Problems related to the development of manufacturing systems have received increasing attention in recent years. This is due in part to opportunities created by technological advances, and in part to growing demand from employees for higher wages, better quality of working life, etc.

Up to now the development of manufacturing systems has been characterized by the engineering approach, where the focus is upon technical or techno - economic factors. In some instances attention has been given to human factors, mostly in connection with the man-machine interface. The intention has been to improve system performance. Often have employee needs been neglected. An illustrative example is the introduction of robots which has brought many advantages such as improved productivity, better quality, less accidents, etc. However, as reported by Korndorfer and Schlichting (1981), in many cases it has also had negative side-effects such as more montonous jobs, extermely short-cycled manual operations, reduction of operator qualifications, reduced possibilities of movement and communication, more shift operations, reduced motivation, and elimination of jobs.

In general, the negative aspects of many manufacturing systems are now so strongly felt that improvement of working life has become a societal concern. An illustrating example is the Norwegian Work Environment Act which requires firms to provide an environment which is satisfactory both from a physiological and psychological point of view.

Several attempts have been made to improve the human aspects of manufacturing systems. Among the best known are job rotation, job enrichment, semi-autonomous groups, and recently, quality circles. Widely known are the Norwegian experiments with work democracy which, according to Elden (1979), have been a great stimulus for futher experiments in this area. The results vary greatly. Some firms have obtained lasting results. Others have had initial success, but gradually the positive effects have disappeared. There are also many firms where the attempts to improve the quality of working life have failed from the first moment. Obviously, there is no patent solution in this area. One can only state that certain approaches have proved to be successful in certain situations; in other cases it appears that those responsible have sold their own medicine rather than finding out what is wrong with the patient.

Most experiments have been introduced in order to remedy weaknesses in poorly designed systems. The thesis of this paper is that the probability of success of a manufacturing system will be increased if proper attention is given to the needs of all concerned at the design stage. In addition to determining technical needs and transforming them into technical requirements by means of economic considerations, one should determine relevant human needs and transform them into human requirements by considering both economic and human factors.

The theoretical background of the author regarding manufacturing system design is not worth mentioning, and his practical experience with design of such systems has been gained in a period where the task was entirely limited to technical and economic factors (a situation that still prevails in many places). When he, in spite of this dares to engage himself in the current effort of finding better approaches to manufacturing system design, the justification lies in his rather wide experience from research, teaching and consulting in connection with product innovation activities. There are many parallels between development of products and development of manufacturing systems. It appears that several concepts and methods related to user-oriented product innovation processes can be of value for assessing human needs in manufacturing system design processes. With rather limited knowledge in the latter field, the following views will necessarily be of a speculative nature. They should be considered more as a contribution to the discussion of finding better approaches than an attempt to give a final answer on how to design an optimal system.

THE SYSTEM APPROACH

When designing a manufacturing system, one may use the system approach, which basically involves consideration of all parts interacting for a common purpose. An attempt in this direction is the

application of the "multi-interest concept", i.e. consideration of the needs of all influenced by the system, whether inside or outside the firm. The most important interests are usually the company, the owners, the employees, the users and the society.

Another aspect of the system approach is the levels involved as illustrated in Figure 1.

As a starting point, the business concept and the major objectives of the firm or the division concerned should be clearly articulated. When a firm or division is organized, it usually has a strong future-oriented concept. However, as time passes, external and internal factors will change. The original concept will gradually become less and less relevant. One should therefore from time to time review the situation and redefine where the company wants to go.

The next step is analysis and possible reformulation of major objectives. Corporate strategies are formulated by combination of several possibilities as indicated in the model. In many firms the result may be a combination which focuses on cost reduction and improvement of existing products and processes, and a diversification strategy with periodic introduction of new products into existing or new markets.

Key decisions concerning manufacturing systems will largely be derived from corporate strategies related to improvement, innovation, expansion and diversification. Thereby technical needs related to new and improved facilities can be determined in broad terms. Attention should also be given to human needs. In addition to psycho-social needs of employees there are a large number of societal needs which should be taken into account.

Having determined relevant technical and human needs and transformed them into system requirements by proper weighting methods, one can formulate a system proposal. This should be evaluated by appropriate decision-makers before being formulated as the final manufacturing system specification.

MANUFACTURING SYSTEM DESIGN

The approach used for designing a manufacturing system will, as indicated above, be influenced by corporate strategies. Thus, if the focus is upon volume expansion or improvement of current products, the traditional problem solving process may be relevant. On the other hand if an innovation or a diversification strategy is adopted, the design of the system may be more like a learning process.

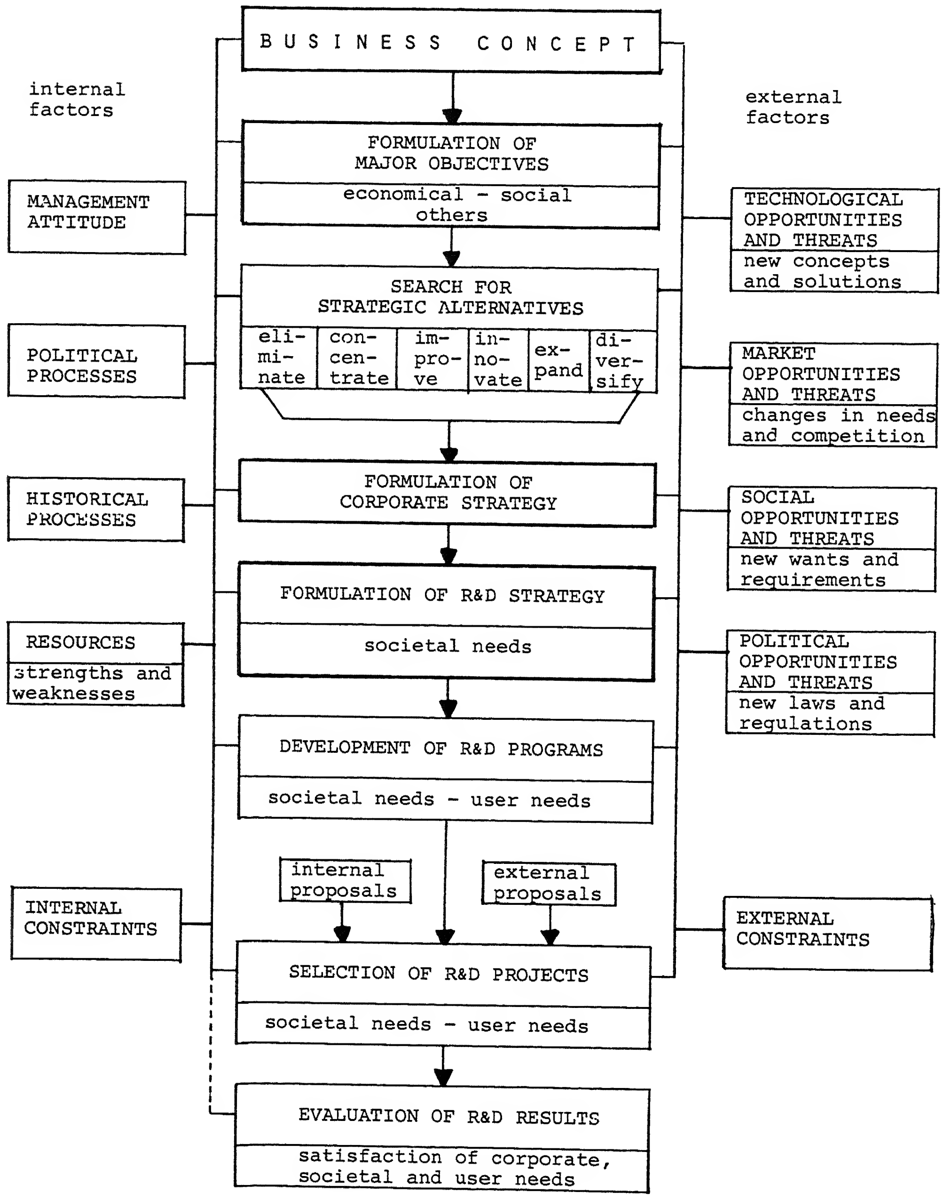

Figure 1. Reference model for descriptive and prescriptive analysis of R & D activities in relation to corporate objectives and strategies.

The traditional problem solving process

This process is derived from the method used by scientists in solving problems in laboratories. Although there are minor variations in its description, these generally start by defining the problem in terms of a desired objective. A common model, referred to by Holt (1982), is indicated in Figure 2.

The first step is the most important since it determines scope and direction of the following steps. A highly simplified model is given in Figure 3. Taking into consideration the needs of those involved and existing constraints and available time, concrete objectives are formulated. If there are not enough resources available, one will have to subdivide the problem and start with the parts given highest priorities.

In actual practice the problem definition stage is often neglected. According to Jackson (1976) this is the part of the problem solving process which is least developed. In most courses the emphasis is upon development and choice between alternatives and implementation of solutions. The importance of defining the problem by asking the right questions is stressed, but little information is given about how to do this.

The traditional approach presupposes a stable situation with complete knowledge regarding solution alternatives and their consequences. One then can formulate a clear objective for the remaining stages. An example of such a situation is the planning of a new factory for production of refrigerators. The manufacturing processes took place in an old and crowded building with functional lay-out. After intensive discussions between those involved it was decided that the plant should be designed and built for a specific volume of production and put into operation within one year. The design was done by the manufacturing staff, assisted by an external consultant. Having a clear objective and thorough

- definition of the problem
- collection of data
- analysis of data
- development of alternatives
- selection and implementation of solution

Figure 2. Model of the traditional problem solving process

- needs (company, employees, users, society, etc.)
- constraints (human, physical, financial, legal, timing, etc.)
- priorities (subproblems according to importance)

Figure 3. Key elements in problem definition

knowledge regarding all technical and economic aspects of the problem, the group was able, within the specified time limit, to analyse pertinent facts, develop relevant alternatives, select a solution, and specify lay-out, facilities and methods for processing, inspection and packaging.

Problem solving as a learning process

In designing manufacturing systems initiated by innovation strategies, one may have to break new ground and develop original solutions (sometimes this is also true for design of manufacturing systems based on product improvement and volume expansion strategies). The design process will then take character of a learning process based on incomplete information. The focus is upon "knowledge development" as emphasized by Normann (1977). He sees planning under uncertainty as a step by step process that starts with a vision, i.e. an intuitive idea of a reasonable future state of the system. Having analysed the consequences of the vision and evaluated the conclusions, more information is acquired and analised, the vision is adjusted, and so on.

One example of such a learning process is the development of a plant for processing pyrite ore. The project was initiated by the chief executive of a mining company that previously had sold its production to ore processing companies. He recognized that it might be profitable to build a plant and process part of the production in the company's facilities. In order to get satisfactory profit he felt that the plant, in addition to getting a maximum of sulphur and copper, also should be able to extract other components of the ore such as iron, silver, etc. A competent metallurgic consultant was retained. Several possible processes were discussed and tried out, first on laboratory scale, and later in a pilot plant. However, a year's intensive work did not bring any tangible results. The direction of the research was then changed, and a larger and rather different pilot plant was built. The new experiments were conducted over two years, but as still no practical results were obtained, the project was abandoned.

After a number of years the idea was taken up again. Now a joint project was organized with a large firm well known for its competence in extracting ore. This time the experiments were conducted in a rotating kiln. However, after a year they were stopped as no significant results had been obtained. A new project leader was brought in. He decided that one should start experiments based on the process originally suggested. After two years of pilot plant operations he succeeded in developing a process which recovered 70% of the sulphur. Further experiments and improvements brought the recovery up to 80%. This result was so encouraging that it was decided to build a plant with an annual capacity of 150 000 tons of ore. The objective was to have the plant completed within one year. However, several delays occurred so actual operations started $1\frac{1}{2}$ years after the decision was taken. During the break-in period several changes had to be made, and finally one was able to extract 75% of the sulphur content, which was considered satisfactory. Almost 13 years had then elapsed since the start of the first experiments. After a few years of production a plant for cleaning of the furnace gas was built. This brought the sulphur recovery up to 85% which was considered to be a very good result.

In situations like the one described, the design of the manufacturing system takes the character of a learning process based on incomplete information. Here it is not possible to start out by defining the problem in terms of a clear objective. The situation was quite different when the board decided to increase the capacity of the plant to 300 000 tons per year. After initial planning, a project schedule was developed based upon completion of the new facility within one year. As the engineering staff had necessary knowledge at hand, the objective was reached without serious difficulties.

When taking human needs into account during the design of a manufacturing system, one may, as emphasized by Checkland (1979), find different and even conflicting views on what is desirable. He claims that the ranking of different needs is a value judgement subject to changing criteria. A typical example is the increased emphasis now given to quality of working life as well as to environmental and ecologic problems. In such situations one is faced with a continuous process of making different views explicit, working out implications, and testing them against other views which may be equally valid within other frames of reference.

Combinations

In actual practice the design situation will most often be someplace between the extremes described above. Thus, one may start and define the problem by formulating a tentative objective, select and analyse relevant facts regarding the situation, move

back and redefine the problem, develop alternatives, collect and analyse facts regarding the alternatives, select and implement solution, redefine the problem, collect new facts, etc.

One example of such a design is found in a chemical company that wanted to diversify its product spectrum by production of sodium alginate. The basic raw material, sea weed, was available in ample supply in nearby ocean waters. After a year of process development in laboratory and pilot plant, the board of the company approved a proposal to build a processing plant. Having clarified the technical and commercial aspects of the project by means of a preliminary study, it was decided that the plant should have an annual capacity of 500 tons of sodium alginate and be completed within a year. The processing equipment consisted mainly of mills, washers, mixers, separators and storage tanks. The various units were connected by means of pumps and tubes. The equipment would be installed in an old two-storyed building that was available after phasing out another product.

Selection, specification and acquisition of equipment, lay-out of manufacturing processes and rebuilding of the plant were completed in accordance with the project schedule. However, at start of the test production serious problems arose in connection with dewatering of crude alginic acid. For this purpose a drum centrifuge was used. An intensive effort was made to get the bugs out of the system, but after two months they concluded that they were not able to reach an acceptable production rate. It was then decided to try a basket centrifuge. In cooperation with a manufacturer of such equipment experiments were undertaken in a pilot plant belonging to the manufacturer. After a few weeks satisfactory results were obtained, and a new separator was ordered. As the delivery time was six months, normal production started almost nine months later than originally planned for.

In such situations the manufacturing system design process will be of a more or less iterative nature. If information is lacking, or not available because of time or cost-limitations, one has to make assumptions and guesstimates.

Problem solving and need assessment

Need assessment will be an important activity whatever method is used for problem solving. Taking the extreme cases, the situation is as indicated in Figure 4. In well structured problems the needs are known, and it is therefore possible to determine them during the problem definition stage. In other cases, eg. when developing entirely new manufacturing systems, the alternatives and their consequences are unknown. Under such circumstances the assessment of human needs has to be done later in the process. In large projects

	SITUATION CHARACTERISTICS	SOLUTION ALTERNATIVES	CONSEQUENSES	NEEDS
TRADITIONAL PROBLEM SOLVING	CERTAINTY	KNOWN	KNOWN	KNOWN AND RANKED
	RISK	KNOWN	PROBABILITY DISTRIBUTION	KNOWN
PROBLEM SOLVING AS A LEARNING PROCESS	UNCERTAINLY	KNOWN	UNKNOWN	PARTLY KNOWN
	PARTIAL IGNORANCE	UNKNOWN	UNKNOWN	UNKNOWN

Figure 4. Problem solving methods and characteristic factors

that take a long period of time, the assumptions may change during the process. One may therefore have to repeat the assessment and update the information as one moves ahead towards completion.

NEED ASSESSMENT

In general, a problem is characterized by a discrepancy between a desired state and the prevailing one that is of such a magnitude that it requires corrective action. The discrepancy depends on the strength and direction of the needs that are perceived and the degree to which they are fulfilled.

It is difficult to make a good need assessment. In order to get results one has to simplify complex relationships by applying proper concepts and methods.

Concepts

The needs related to manufacturing system design can be classified as shown in Figure 5. The human needs can be divided into two groups. The individual needs refer to needs perceived by employees. They are based on a widely, but somewhat controversial theory of motivation where the underlying assumption is that needs can be arranged in a hierarchical order (Maslow 1954). At the bottom are physiological needs. Unless satisfied, they remain the prime

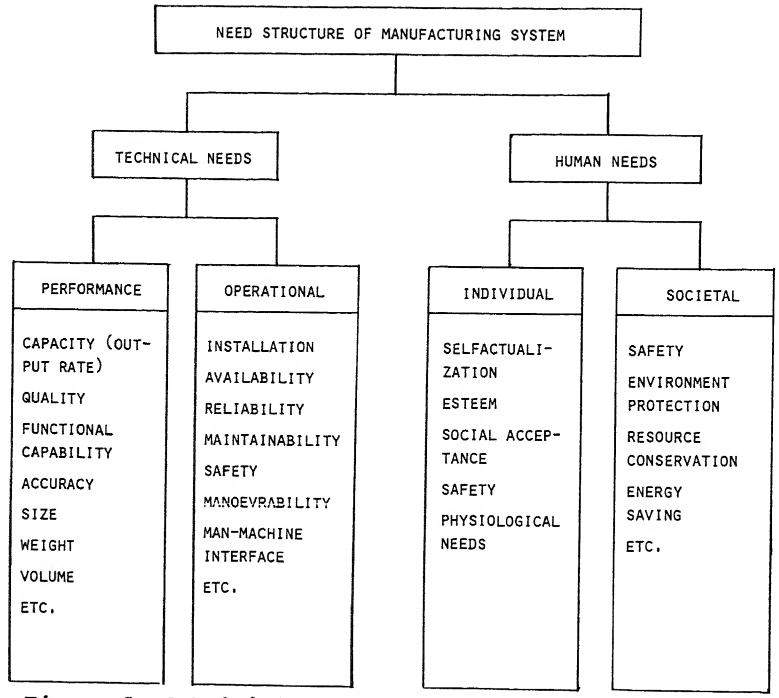

Figure 5. Subdivision of manufacturing systems needs

motivator. When satisfied, safety needs emerge with greater strength.

A great number of employees still have an unsatisfactory work situation manifested through fatigue, bad health, accidents, etc. This situation is improving, and for many employees in industrialized countries lower level needs are satisfied by adequate wages, safe working conditions, etc. These needs are then considered to be hygiene factors, or even human rights. Frustration results if they are inadequately covered, but they do not motivate behaviour (Herzberg 1966). Next on the hierarchical ladder are social needs including belonging, friendship, affection, love, etc. At the highest levels come esteem needs such as self-respect, status, etc., and self-actualization needs such as self-development, self-expression, creative behaviour, etc.

The model of individual needs represents a simplification of a complex reality. Usually there is a multiple motivation caused by interaction of several needs, some of which may have opposing effects. The needs also vary over time, from country to country, from organisation to organisation, from group to group, and from person to person (Campbell and Pritchard 1976). However, used carefully, the model has proved valuable for diagnostic purposes.

The <u>societal needs</u> refer to an increasingly important group,

the needs in the society outside the firm. Great attention should be given to such needs when designing manufacturing systems.

Human needs can be classified as existing needs, based on a recognised discrepancy between an existing and a desired situation, and future needs, i.e. needs which do not exist, but will materialize in the future.

As employees are aware of existing needs, they are relatively easy to assess. For example, in work situations where physiological needs and safety needs are far from being fulfilled, they are easily recognized by those involved. This is a typical situation for employees in many developing countries where basic physiological needs such as water, food and protection against elements are far from being fulfilled. Under such circumstances, higher level needs are of a future nature. As a country develops, these needs will be felt increasingly and influence the design of manufacturing systems. The faster the growth, the sooner future needs will materialize.

Due to rapid political, social, economic and technological developments it is important to assess future needs. This is particularly true in connection with the design of manufacturing systems involving development of new technology, which may be a rather time-consuming process.

In some cases it may be useful to distinguish between rational and emotional needs. The rational needs are mainly related to the functioning of the manufacturing system and cover safety, physiological load, psychological load including perceptual load, and environmental conditions such as heat, cold, noise, vibration, dust, and chemical substances. Because of negligence of such needs capital equipment often suffers from a "quality gap", i.e. a gap between desirable and actual characteristics. In such cases new solutions may be required in order to satisfy human needs.

The emotional needs are concerned with non-technical factors such as status, contact with others, appearance, shape, style and colour of equipment, etc. They may have a great impact on human well-being. Also technical factors may be of an emotional nature, eg. malfunctioning of equipment.

Tools for need assessment

With increased focus upon human needs in design of manufacturing systems the selection and application of proper methods is a vital task. Several tools are listed in Figure 6 that may be used in this context. They have been selected among 27 tools for assessment of user needs in product innovation processes (Geschka et al 1981). Broadly they can be divided into two groups:

	METHODS \ NEEDS	RATIONAL		EMOTIONAL	
		EX	FUT	EX	FUT
EXISTING INFORMATION	1. COMPANY STUDIES: REPORTS FROM ATTITUDE SURVEYS, CLIMATE MEASUREMENTS, ETC.	X		X	
	2. GOVERNMENT INFORMATION: SURVEILLANCE OF CURRENT AND ANTICIPATED REGULATIONS	X	X		
	3. LITERATURE: PRINTED MATERIAL SUCH AS BOOKS, JOURNALS, SPECIAL REPORTS, ETC.	X	X	X	
	4. COMPETITOR INFORMATION: COLLECTION OF INFORMATION CONCERNING COMPETITOR'S MANUFACTURING SYSTEMS	X		X	
	5. TRADE FAIRS: COLLECTION OF MANUFACTURING SYSTEM INFORMATION AT FAIRS	X		X	
	6. EXPERTS: SYSTEMATIC QUESTIONING OF SOCIAL SCIENTISTS AND OTHER KNOWLEDGEABLE PERSONS	X	X		
GENERATION OF NEW INFORMATION	7. QUESTIONING: PURPOSEFUL COLLECTION OF DATA FROM EMPLOYEES THROUGH INTERVIEWS AND QUESTIONNAIRES	X		X	
	8. OBSERVATION: OBSERVING, RECORDING AND ANALYSING BEHAVIOUR OF THOSE INVOLVED	X	X		
	9. ACTIVE NEED EXPERIENCE: ANALYST WORKING A CERTAIN PERIOD IN A RELEVANT ENVIRONMENT	X	X		
	10. SIMULATION: PERFORMING OR OBSERVING WORK IN A SETTING WHERE A REAL LIFE SITUATION IS CREATED	X	X	X	
	11. CREATIVE TECHNIQUES: BRAINSTORMING, BRAINWRITING, USER DELPHI, MORPHOLOGICAL ANALYSIS, ETC.	X	X	X	
	12. DELPHI TECHNIQUE: SUCCESSION OF ITERATIVE STATEMENTS IN WRITING BY PARTICIPANTS		X	X	X
	13. SCENARIOS: DEVELOPMENT OF ALTERNATIVE FUTURES OF THE ENVIRONMENT OF THE MANUFACTURING SYSTEM		X		
	14. SYSTEM ANALYSIS: ANALYSIS OF MANUFACTURING SYSTEM REQUIREMENTS FOR FUTURE SYSTEM PRODUCTS		X		
	15. SAFETY ANALYSIS: ANALYSIS OF ACCIDENTS AND HAZARDS THAT MAY CAUSE INJURY AND DAMAGE	X			
	16. ECOLOGICAL ANALYSIS: ANALYSIS OF ENVIRONMENTAL CONSEQUENCES OF PROPOSED PROCESSES	X			
	17. RESOURCE ANALYSIS: ANALYSIS OF RESOURCE UTILI- CATION OF PROPOSES PROSESSES	X	X		

Figure 6. Tools for need assessment in manufacturing system design

- utilization of existing information; this is usually a cheap way of getting need related information. The major problems are to locate the most important sources and collect relevant data.

- generation of new information; this approach requires relatively great effort. It is usually a more expensive way of assessing user needs as special activities have to be planned and implemented. On the other hand, the information obtained in this way is usually more relevant, complete and reliable.

In the figure some information is given referring to the practical application of the various tools. It is distinguished between rational and emotional needs, and between existing and future needs.

Most of the methods listed are primarily related to the assessment of employee needs. The two last methods refer to assessment of societal needs.

With present knowledge it is not possible to give guidelines concerning the amount of resources that should be devoted to need assessment, and what tools should be applied in specific cases. However, considering the importance of information about human needs careful consideration should be given to this matter in order to achieve a proper balance between technical and human factors. By doing so, the negative effects of technology on environment and quality of working life can be eliminated or reduced.

CONCULSION

In order to develop an optimal manufacturing system both technical, economic and human needs should be taken into consideration. Whereas one has a solid and rapidly advancing body of knowledge about technological factors, the situation is quite different for human factors. In order to make progress here, both theoretical studies and practical experiments are needed. However, the situation should be no excuse for a "wait and see" attitude. There are several need assessment methods available that can be used for practical purposes. However, need assessment is more than selection of methods. It is a question of organization, and above all, of attitudes. In order to be in tune with social and political trends, an attitude which takes into account human needs is required.

To change attitude is a difficult task. Perhaps the most efficient way is to replace narrow-minded key personnel by people with the desired attitude. In most cases this is not practicable. An alternative approach then is to supplement technical experts with human-oriented staff like industrial engineers, ergonomists,

behavioural scientists, etc. In addition one should stimulate all involved in design of manufacturing systems to learn, experiment and apply various need assessment methods. The ultimate proof of the value of these methods can only be determined by experience, and experience can only be gained through practice.

As a short-term effect of applying need assessment methods human factors will automatically be brought in the foreground. In addition, a long-term effect will be to develop a more humanastic attitude.

Greater emphasis upon humanization represents an expansion of the traditional efficiency concept. Briefly it can be expressed in the following way:

$$\text{real efficiency} = \frac{\text{output + human satisfaction}}{\text{input + human satisfaction}}$$

It is not possible to quantify this model. However, it indicates that real efficiency can be less than calculated by the traditional approach due to decreased satisfaction or increased frustration. Thus, if human factors are neglected at the design stage, the result may be different from what is expected. On the other hand, measures that improve the situation for those involved may lead to better results in the long run. In several cases humanity and traditional efficiency will run parallel. However, there are also cases where they are in conflict. It is then important not to forget the human aspects. However, one should be careful not to let the pendulum swing too far to one side. One should not be so preoccupied with soft values that technological factors are neglected; this may in the long run be detrimental to the efforts of designing an optimal manufacturing system. What is required is a balanced view where all aspects are taken into consideration. The challenge is to develop a system that is technologically feasible, economically profitable, and socially acceptable.

ACKNOWLEDGEMENTS

The author expresses his thanks to Stein Andersen, Linn Moe and Thor Paasche for valuable comments.

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MANUFACTURING LEAD-TIMES: A KEY CONTROL FACTOR FOR THE PRODUCTION/MARKETING INTEGRATION IN SMALL COMPONENT-MANUFACTURING FIRMS

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INTRODUCTION

Metals manufacture is a fragmented industry with a few large and many small firms. Large firms like those of the aircraft and heavy automotive industry use a great number of small manufacturing shops as subcontractors for components of their final products. These jobbing component-manufacturing firms, for example engineering shops for machined and fabricated components, foundries etc., are producing entirely according to customers' specifications, so that no product standardisation is possible. Most of the jobs are for one-piece components released in small batches. The production means have to be flexible enough to suit a great variety of both items and orders.

These shops sell to their customers not only an item made to desired specifications at an agreed price but also an item delivered at a specified time. Two aspects of this delivery time are important:first the length of time between the placing of an order and its delivery, often called "lead-time", and second, the reliability of delivery at the requested or agreed time often called "meeting due-dates". Planning values for manufacturing lead times are of equal importance to the production and to the marketing functions in the medium-term. Procedures like capacity planning, machine loading (production), quoting delivery dates (marketing) as well as considerations about the customer's satisfaction due to short lead times and reliable due-dates (marketing), capital tied-up, capacity utilization, overtime and expediting costs (production), are all based on planning data about manufacturing lead-times.

A production/marketing integration in the medium-term has to be based on this key control factor. Without coordinated management of manufacturing lead-times a rational balancing of market needs and production costs will not occur.

AN OVERVIEW OF PLANNING DECISIONS AND REQUIRED PLANNING DATA.

A job shop requires a vast number of decisions to be made in order to keep it in operation. These decisions vary in importance from "should we buy another horizontal milling machine?" to "should we accept such a large order for delivery in eight weeks?" to "what job should John Smith work on next?".

Holstein (1968) presents an overview of the hierarchical set of decisions needed in a general production facility, and this list with some minor revision by Swimer (1972), could be applied specifically to a job shop.The following set of decisions is proposed:

(a) Long term capacity planning (horizon of one or more years) which involves the major adjustments of plant capacity to match projected requirements.

(b) Medium term production planning (horizon of one or more months) which matches the available capacity to individual customer orders as well as making minor adjustments to the available productive capacity (e.g. work force size changes, use of overtime).

(c) Short term scheduling (horizon of one or more weeks) which includes the more detailed plans which ensure that the delivery commitments are met.

(d) Dispatching and shop control (horizon measured in minutes or hours) which includes the problems of detailed information gathering (e.g. the current status of job XYZ) and the immediate decisions regarding what task a particular worker does next.

The long term decisions (a) are made in the light of the strategic posture taken by the firm. The extent to which a given firm is ready to deal with variety of different products or to depend on one or more customers or industries is related to the configuration of the shop itself. Here the problem is, given the market for products and the present shop facilities, to find (approximately) the best mix of products and customers; further, given the possibilities for changing the shop facilities, for example by purchase of machinery, to adapt the shop to the market so that the resulting changes constitute good or perhaps "best" long

term improvement in the position of the business. In make-to-order shops, the planning data for such strategic decisions can never be formal forecasts of future demands. However, information about the state of the economy and its impact on the company's future business is a vital ingredient in plans for the future.

The medium term and short term decisions (b) and (c) are also subject to both production and marketing considerations. The marketing objectives are:

- As big a sales volume as possible
- Short delivery lead times
- Reliable due dates

The first two objectives mean that as many customer orders as possible will be accepted to be delivered as soon as possible. This attitude overloads productive capacity in the short term, comes in contradiction with production planning objectives, and endangers the reliability of due dates.

The production planning objectives are:

- Short flow-times (low capital tied-up)
- High and smoothly balanced capacity utilization (low manufacturing costs)
- Meeting due dates

The first two objectives are contradictory since a high degree of capacity utilization can only be achieved through the existence of queues and longer waiting times for shop orders. Because the costs of idle capacity are usually higher than the capital tied-up costs, the capacity utilization criterion always comes first in production planning considerations (Kettner, 1976).

The integration of production and marketing is needed for the rational balancing of all the above described objectives in the following problem (Reiter, 1966) : "...To negotiate the timing of deliveries with customers on a realistic basis reflecting the presence of other orders, the capabilities of the shop, and the "costs" of achieving a certain timing, as well as the value of the timing to the customer".

This task needs an integrated capacity planning procedure to control the rate of incoming orders and the level of work in the shop through the Customers Orders Planning and Shop Orders Release

functions. The required planning data are:

- Capacity data
  - Personnel, machines
  - Load reports

- Engineering data
  - Routing sheets
  - Bills of material

- Lead times data
  - Suppliers' lead times
  - Manufacturing lead times
    - Transit times between operations
    - Safety time buffers

Successful planning does not depend only on the used procedures. An equally decisive factor is the quality of the basic planning data. The quality criteria are their currency, accuracy and value for futute planning. The main sources of quality problems among the above described planning data are the load reports and the planning values for transit times between operations. Small firms often do not have the will or the ability to stand the labour costs for efficient collecting of shop-floor feedback data and updating of planning data. In this case, capacity planning procedures should be designed in order to be able to work with a choosen level of data aggregation. The recent appearance of relatively cheap on-line shop-floor data collecting systems suitable for small and medium sized firms (Kittel, 1981), is bound to improve the currency factor, which is crucial for good load reports. However, it is not enough for the future planning values of lead times. Most people believe that they need a system capable of responding more quickly and precisely, changing planned lead-times to match the actual lead times experienced. As will be shown in the next section of this study, nothing could be further from the truth.

FACTORS THAT INFLUENCE MANUFACTURING LEAD TIMES. TWO HIDDEN VICIOUS CYCLES.

In intermittent production systems, manufacturing lead times are dominated by the transit times between operations. About 90% of the total flow time is due to transit times (85% queuing, 3% quality control, 2% transportation) and only 10% is due to actual processing of operations (Stommel, 1976). Therefore, the problem of estimating manufacturing lead times is mainly a problem of discovering the underlying factors that influence those inter-operation transit times.

According to Heinemeyer (1974), those factors may be classified

as short-term, medium-term and non-quantitative. Examples of short-term influence factors are the batch quantity, processing time, set-up time, priority rule, due date, etc. The research arrived at the conclusion that none of these factors has a severe influence on transit times and that far more important are the medium-term factors:

- Backlog of work in the shop

- Capacity planning method

While the role of the backlog of work in the shop as a major factor influencing queuing times is easily understood, the role of capacity planning methods is often not recognized. By capacity planning method we mean a capacity planning strategy together with the required planning data. Stommel (1976), gives a detailed account of existing capacity planning strategies. A fundamental difference exists between operations-oriented and order-oriented strategies. According to the latter class of strategies, a shop order is not released unless capacity is available for all its operations. The order remains close together and shorter transit times between operations are achieved. However, this reduction is at the cost of longer waiting times in the "pool" of non-released planned orders, where all orders stay from the time that material becomes available until they are actually released to the shop. Since non-released orders have low value (raw material only), the strategy leads to lower capital tied-up. On the other hand it allows less flexibility to the foreman for day-to-day capacity balancing decisions.

Differences in existing capacity planning strategies have an influence on the time that a job spends on the shop-floor, which is important for production control. However, they make no difference for the total time that a job spends in the shop, as this includes the time elapsed between the arrival of material and the actual release to the shop-floor.This total lead time is of interest to the marketing function. An integrated capacity planning strategy should provide for controlling lead times at all levels.

Almost all standard software packages base their capacity planning strategies on mean planning values for transit times from one machine group to another (transition matrices "from-to"). These quite often inaccurate values result in false reservations of capacity, therefore false balancing, overloads, increased in-process inventories, increased lead times, missing due dates and, finally, even greater inaccuracy of planned transit times. This vicious cycle (Kettner and Jendralski, 1979), is related to the Release Function.

Another vicious cycle, reported by Mather and Plossl (1977) as

the lead time syndrome, is related to the higher level function of Customer Orders Planning. Increased rate of incoming customer orders inflates lead times, planning values for lead times are updated to reflect the latest situation in the shop, and longer lead times are quoted. Customers react by releasing more orders to cover the requirements during the increased lead times and lead times are further inflated, the shop decides to increase its capacity, lead times drop, the customers release fewer orders, capacity is decreased and the cycle starts again.

All this proves that a system capable of updating quickly planned lead times to match the actual lead times experienced is not enough, since it does not help in avoiding the lead time syndrome. What is needed is a system to control the level of work in the shop not only at the release level but also at the higher level of quoting delivery dates. Such a system can only work through a production/marketing integration in controlling a hierarchy of backlogs of work and their relevant lead times.

A HIERARCHY OF BACKLOGS AND LEAD-TIMES

Lead time in practically any company is a function of backlog (Plossl and Wight, 1973). However, if lead times are to be controlled, there is a problem of finding which part of the total delivery lead time is a function of which backlog. A set of definitions is given for all the parts of the total delivery lead time and the backlogs responsible for them.

Firm customer orders waiting for material, non-released shop orders, released shop orders and queues of items waiting for particular machine centres, form a hierarchical chain of backlogs responsible for a consequent hierarchy of lead-times (Fig. 1).

Definitions

Total Backlog: The backlog of all jobs in the shop, whatever their status may be.

Planned backlog: The backlog of all jobs with material available, either planned but non-released or released to the shop-floor. Firm jobs waiting for material are not included.

Pool: All planned jobs waiting in the "pool" (Irastorza and Dean, 1974) of non-released jobs.

Released backlog: The backlog of all jobs released to the shop-floor. It includes the sum of the processing times for all the jobs on all their operations in their job sequence yet to be carried out.

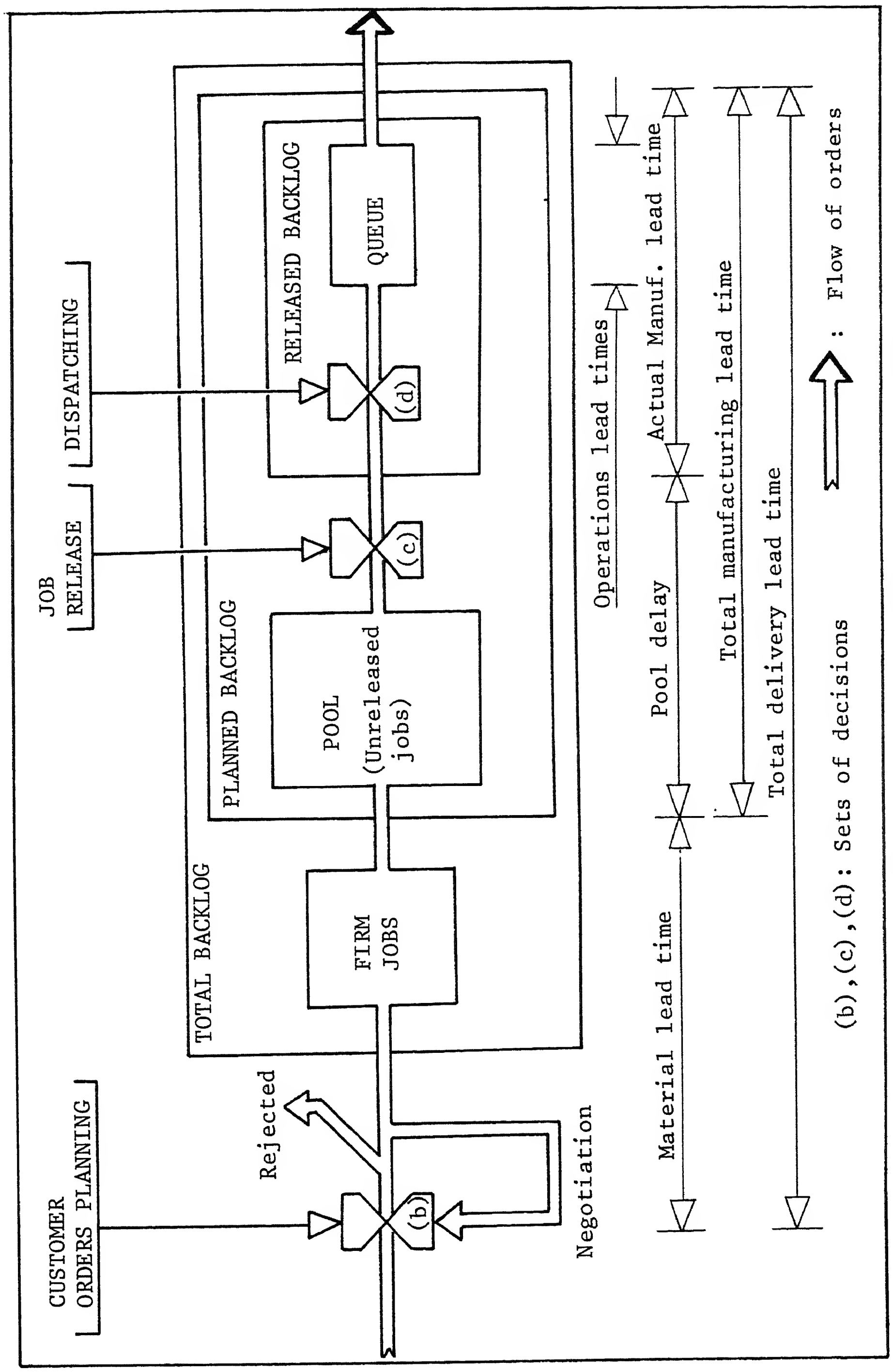

Fig. 1. The hierarchy of backlogs and lead times

Queue: The sum of processing times of the next operation of all items waiting for particular machine centres. It is only a part of the "Released backlog".

All the above definitions of backlogs may be related either to a particular machine centre or to the shop as a whole.

Total delivery lead time: The time elapsed between the confirmation of a customer order and its delivery.

Material lead time: The time elapsed between the placing of a purchase order and the arrival of material.

Total manufacturing lead time: The time elapsed between the arrival of material and the delivery date. It is a function of the "Planned backlogs".

Pool delay: The time that an order spends in the "pool" of non-released shop orders. It is a function of the "Pool".

Actual manufacturing lead time: The time elapsed between the release of an order to the shop floor and its completion. It is a function of the "Released backlogs".

Operation queuing time: The delay of the order between successive operations due to the "Queue".

GUIDELINES FOR AN INTEGRATED PLANNING SYSTEM

A production/marketing integrated planning system should manage lead times to desired lengths by controlling all backlogs in the hierarchy. Simulation with actual data of the particular shop could help in determining the consequences of various backlog levels on lead times, capacity utilization and work-in-process inventories (Kettner and Jendralski, 1979; Michael, 1976). The task of integration is considerably easier in small firms where there are no organisational and behavourial difficulties due to clearly set boundaries between the marketing and the production control departments, as can happen in larger firms. A small computer system easily accessed by a small number of people responsible for both functions may be enough. The following general guidelines would facilitate the design and implementation of such a system:

- The system should be interactive. Either man or computer alone have been proven inefficient to deal with the immense complexity of the problems involved (Godin, 1978). In particular the marketing function has an important non-quantitative dimension which makes intervention by the experienced manager inevitable.

- Capacity planning algorithms should not exceed the computational ability of a microcomputer. Running times of the various parts of the program should be short enough to facilitate a dialogue between the user and the computer.

- The system should manage the actual lead times to match the planning data instead of updating the planning data to match the actual lead times experienced.

- Every effort should be made to investigate the possibility of installing an on-line shop-floor data collecting system suitable for small firms (for example Malsbender, 1978). If the firm has not the will or the ability for this investment, then the co-existence of a computerized planning system with a manual shop-floor collecting system is feasible only by choosing an aggregation level for data input, so that typing-in of chaotic detailed information from hand-written reports is avoided. Consequently the capacity planning algorithm should be adapted to work with aggregated data.

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MANUFACTURING MANAGEMENT:

EFFECTS ON PRODUCTIVITY AND QUALITY

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To say that the quality of manufactured goods like integrated circuits or automobiles depends on top management, its commitment to quality as a goal, is a truism that hides more than it reveals. Management control can be credited or blamed, within bounds, for virtually any measure of corporate performance -- from return on investment, to labor productivity, to the mean time between failures for a microprocessor chip. The specific techniques that managers use in pursuit of these ends, their priorities among goals that may conflict, the ways in which they help to motivate the firm's employees, are more telling. This paper examines several of these, concentrating on the management of manufacturing operations broadly construed to include such matters as the interfaces between product engineering and production engineering.

THE EXAMPLE OF AUTOMOBILE PRODUCTION

As the evidence began to mount that the American automobile industry was losing competitiveness on a variety of dimensions, compared especially to Japan, manufacturing costs and productivity quickly became a focus of attention. At first, the wage rate differential between autoworkers in the two countries seemed the major factor.[1] Lacking quantitative data on productivity -- i.e.,

*The views expressed in this paper are entirely those of the author and are not necessarily those of the Office of Technology Assessment.

labor hours per vehicle -- a number of estimates of manufacturing cost differences assumed the labor content to be the same and the Japanese cost advantage to come from lower pay scales. On this basis, manufacturing costs would be $500 to $1000 less in Japan for roughly comparable subcompact cars. While shipping costs might be $500, Japanese imports would still have competitive delivered costs.

But in fact, the imports appeared to have a greater cost advantage, at the factory gate perhaps $1200 to $2000.[2] American manufacturers claim these lower base production costs allow Japanese automakers to put more effort and more money into quality control -- particularly "fits and finishes" -- as well as into optional equipment, thus enhancing the attractiveness of their products to American (and European) consumers.

What might the sources of such large cost differences be, beyond the relatively well-documented wage patterns? Estimates have been confounded by a lack of appropriate productivity measures, and by the proprietary nature of the manufacturers' own cost data. Moreover, even "comparable" automobiles are not the same; careful attention to detailed engineering design is one road to lower costs. Vertical integration varies considerably within and between the two countries. While Japan's automakers are not highly integrated in the usual sense, the close working relationships that exist between assemblers and their suppliers -- many affiliated closely or loosely --evidently substitute to a considerable extent for internal production as it occurs in a more highly integrated American firm like General Motors. But both wage levels and labor productivity will vary across suppliers and assemblers, whether nominally independent of one another or part of the same enterprise. Many such factors must be considered in the cost analyses.

As the evidence has continued to mount concerning production cost differences and their sources, a variety of factors that can be loosely grouped under the rubrics "manufacturing management" or "manufacturing efficiency" have come to the fore.[3] In essence, this means how a company utilizes the talents of the people it employs -- not only on the factory floor, but in the engineering and clerical offices, indeed throughout the organization. In such contexts, questions such as the Japanese "work ethic" or the management styles of Japanese corporations have often been dealt with in rather impressionistic fashion.

MANAGEMENT IN JAPAN

Japanese firms in a good number of industries -- steel, cameras, consumer electronics and semiconductors, as well as motor vehicles -- have, of course, shown they can make products at high productivity levels and competitive costs, as well as to consistently high quality standards. While some observers stress cultural factors among the reasons for high performance as measured by such indicators, it is easy to overemphasize these. To say that Japanese firms achieve high productivity because their employees work long and hard, or high quality because factory personnel are painstaking and diligent, is not very enlightening. After all, the common techniques of management -- whether on the shopfloor or at the level of the corporate finance committee -- along with those for quality control and manufacturing engineering, are part of a body of knowledge accessible to firms throughout the industrialized world. Given the wide variability that exists within a given country -- whether Japan, the United States, West Germany -- indeed, within a given organization, company-specific variables must have first-order importance. It is no surprise to find that successful, internationally competitive firms in various parts of the world -- Hewlett-Packard, Hitachi, or Nixdorf -- share certain management traits, may differ less than a Philips and a Siemens.

Nor is there any mystery about many aspects of labor relations in Japan. The multitier labor market, the so-called lifetime employment system (which only applies to male employees of large companies, perhaps a third of the labor force), seniority-based pay scales -- all have their basis in rational organizational principles.[4] Patterns of education and training for employees of large enterprises -- whether factory workers, technical professionals, or managers -- can be traced to historical roots in the development of the Japanese economy, particularly the rapid industrialization beginning in the latter part of the 19th century.[5] Company-run training programs for engineers, for example, have risen in part to compensate for the relatively poor quality of university-level engineering education in Japan.[6] Private companies were forced to support internal vocational training and development efforts because of the lack of publicly-financed alternatives, as well as periodic shortages of skilled labor.

Beyond this, at the level of individual firms, are there

other systemic differences between Japanese and Western enterprises -- differences that affect quality, productivity, manufacturing efficiency, industrial competitiveness? There in fact appear to be several -- associated mostly with the extent to which employees, particularly at the lower levels, actively participate in decision-making. This, of course, is the essence of the widely publicized "quality circle" technique.[7]

Participative management is not new -- the "human relations" school of management is well-known to students of management style and practice.[8] But whereas in the West employee participation often gets little more than lip service, a greater fraction of large, globally-oriented Japanese corporations seem to act on its tenets. That is, on the average -- and keeping in mind the great degree of variability that characterizes management style <u>within</u> any one country -- Japanese managers probably stress employee participation more than those in most other nations. This does not necessarily apply to the second and third tier firms in Japan -- where employees have little security, and managers little incentive to invest in the longer term development of their work force. Nor does it mean that some Western firms don't diffuse responsibility broadly through their organizations. And some American firms listen to their employees much more closely than others. But despite the paternalistic trappings associated with the stylized picture of Japanese management -- including the enterprise unions which many in the West would accuse of helping management co-opt workers -- the emphasis on employee participation and the development of human resources does seem to pay dividends. In addition, there are structural differences with potential effects on manufacturing costs and efficiency.

ORGANIZATIONAL PATTERNS AND DIVISIONS

Managing the interface between design engineering and manufacturing engineering presents a classic set of problems -- problems that existed long before the slash in CAD/CAM -- which affect productivity and manufacturing costs as well as quality and reliability. (Quality and reliability are used here in their conventional engineering senses: quality as fitness for function, the degree to which a product meets the specifications set down by its designers and the extent to which those specifications are appropriate to the actual service environment; reliability as failure rate, with failure defined in terms of loss of fitness for function.) Designers specify the characteristics of products in detail, while manufacturing engineers must determine how to make the product so that it will meet these specifications -- a closely related activity, but one often functionally separated within the organization; while sometimes the same people are involved, more commonly the responsibilities fall on separate departments.

Separation of responsibility for design, production, and quality control characterize manufacturing organizations all over the world, but perhaps more so in the United States than elsewhere. One reason appears to be the heritage of scientific management, a movement begun in the early part of the century by the American engineer Frederick Taylor.[9] More broadly, the divisions mirror those found in many places within large corporations, whatever their nationalities, divisions that developed as these new and different organizations evolved around the turn of the century.[10]

The distinctions between those who plan and those who do the work are nonetheless more sharply drawn in the United States, perhaps one of the legacies of the business school training so many American managers now receive. In contrast, their counterparts elsewhere continue to move into management in greater numbers from other professions, even through the ranks, bringing with them a more concrete sense of how the enterprise actually functions. This division between planners and doers -- and the equally sharp distinctions between those responsible for production or "operations" and the rest of management -- has increasingly come under scrutiny and criticism in the United States.[11]

No matter that on organization charts the design, manufacturing, and quality functions may be isolated from one another, these activities will always be highly interdependent. Product design affects choices of manufacturing technologies and costs of production, as well as the quality and reliability of the goods produced. The gradual changeover from steel forgings to iron castings for automobile engine crankshafts is only one example; improved casting technology and metallurgy -- not at all the same thing -- were necessary before the fatigue resistance of nodular iron castings, coupled with the well-established cost benefits, were adequate to the demands of this application. In addition, the manufacturing equipment that a firm has in place -- compared with the costs of investing in new equipment, helps shape the design of its products.

More broadly, a company's "know-how" in manufacturing will heavily influence its product line. The interactions between design and the manufacturing process are particularly vital for large-scale integrated circuits; circuit design depends critically on process capability, and semiconductor firms compete on the basis of proprietary process technologies as well as product characteristics, costs and prices, and quality. Process capability affects all of these. And in every industry, quality and reliability depend not only on design, inspection, and testing but on the choice of manufacturing technologies.[12] The alpha

particle-induced soft errors that afflicted integrated circuit memories a few years ago, primarily 16K RAMS, were cured by a combination of design changes and process modifications.

Finally, from the traditional viewpoint of statistical quality methods, overall control of the process is vital, with primary application to the control of individual steps in manufacturing such as forging, turning, and other machining, forming, and joining operations. The usual goal of process control is to achieve uniform and consistent production, holding variations in measureable parameters within prescribed limits. A major part of the problem is in fact finding parameters that both correlate well with the desired product characteristics and can be simply and reliably measured. Dimensonal control is straightforward, but process control in integrated circuit manufacturing remains very much an art form. It is one thing to measure the hardness and diameter of a shaft turned on a lathe, or even the chemical composition of the steel from which it is made, and quite another to detect minute flaws that may lead to premature fracture through fatigue or stress-corrosion. The hardness test is a poor surrogate even for simple tensile properties. Nondestructive testing and inspection, of which flaw detection and hardness testing are only two examples, will be key elements in future advances in the overall technological capability of manufacturing systems.

MANUFACTURING ENGINEERING

Production and/or manufacturing engineering includes all the technical aspects of the manufacturing process: plant layout, process design, work methods, selection of equipment, quality assurance. In larger firms some of these functions may fall in different departments, in part because of the broad range of disciplinary skills -- as indicated by the examples above -- that may be involved.

Engineering schools in the United States have been derelict in teaching some of these, indeed derelict in their near-total neglect of manufacturing engineering over the past two decades. The post-Sputnick turn toward engineering science came at the expense of the older traditions of engineering design and production. Both traditions now need reinvigoration, but particularly manufacturing. The revival -- which in fact has begun -- should be grounded in the modern engineering sciences including control theory, the physical bases for nondestructive inspection and testing, applications of microprocessor-based systems, the materials sciences and their relevance for improvements in the ways we shape, cut, bend, and weld metal (as well as polymers, composites, and ceramics). Manufacturing

studies need to build on these disciplines, in real time rather than lagging decades behind.

Only a few engineers in the United States get much formal training in manufacturing, or for that matter in design. With few exceptions, engineers who choose to specialize in design or manufacturing are expected to learn on the job, building from an educational base that emphasizes analytical skills. But because both design and manufacturing in the United States tend to have low prestige and low pay relative to other categories of engineering, the best people are seldom attracted to such work. Both fields have higher status in European and Japanese corporations.[13] And, on the manufacturing side of an American firm, quality control tends to be at the bottom of the pecking order.[14]

From the organizational standpoint, as mentioned earlier, the interface between design and manufacturing is critical. While some designers acquire experience in manufacturing, and some manufacturing engineers have worked in design departments, this is more the exception than the rule in the United States. Typically, an American engineer who has chosen a career in design will know relatively little of manufacturing. Manufacturing engineers follow similar patterns -- the result not only of the separation of these activities within the firm but of the lack of formal training in engineering schools. In addition, the designer may have little familiarity with principles of reliability engineering, with quality control and inspection techniques, or with marketing. Manufacturing specialists are often largely unaware of the ways in which variations in the process affect the functioning and performance of the items they are charged with producing.

In some companies, even simple communication is lost. Stories of design and production supervisors who are not on speaking terms are rife, as is the commonplace of the design group "tossing the drawings over the wall" to the manufacturing department. Of course this happens in other parts of organizations as well. But there is at least anecdotal evidence that firms in other countries may handle, not only the problems of training design and manufacturing personnel, but of managing the interface between design and production, better than many American companies. A common approach is simply to make the same individuals or groups responsible for both functions, or at least extend managerial responsibility for integrating design and manufacturing efforts farther down into the organizational structure. In Japan, for example, companies often rotate design engineers through production departments early in their careers.[15] Not only do Japanese firms tend to stress integration of product

and process design within their organizations, but they frequently attempt to involve vendors, distributors, and customers in the work of their manufacturing engineers. Of course, some American firms and industries have grappled with matters such as those outlined above more successfully than others.

Managing for Quality

Deep divisions often exist within the manufacturing function as well -- i.e., between those responsible for production and those responsible for quality. Adversarial relationships among manufacturing managers, quality control personnel, and production workers are often blamed for quality problems. Too often, it seems that manufacturing managers view quality control as an obstacle -- an attitude that is evidently largely absent in Japan, where some executives even profess to be mystified when asked about the costs of quality assurance programs.[16]

American management has indeed been criticized for overemphasizing the short-term costs of quality, whereas some quality control specialists argue that a comprehensive program for designing and building quality (and reliability) into the product at all stages can save money over the longer term. Again, there seems to be a contrast with the typical attitude in Japanese companies, or at least the rhetoric that we in the West hear, where prevention of defects is emphasized more strongly than detection through inspection. Given the relatively large body of knowledge concerning quality and reliability, much of it developed in the United States, the situation in many American firms seems one in which theory and practice have diverged.

The managements of Japanese manufacturing companies do in fact appear to have become convinced that improvements in quality and reliability will automatically cut costs and increase productivity, as well as aiding their marketing strategies. Top managements in Japan often appear to emphasize quality more than their counterparts in the United States. Japanese manufacturing companies rely much more heavily on line managers for quality assurance rather than the staff specialists common in large American firms. Despite these differences, most of the methods that Japanese manufacturers apply in pursuit of quality and reliability have thus far been borrowed from the West, just as occurred with product technologies. (Japan will no doubt be making a greater proportion of original contributions to both product and process technologies in the future.)

Although quality circles have had more visibility than other techniques of Japanese manufacturing management, they are only one

tool among the many that firms there have applied. A common step taken in many plants producing products like television receivers has been to dispense with some fraction of in-process inspectors, instead making each worker responsible for accepting or rejecting parts that pass through his or her work station. This is only one example of diffusion of responsibility through the organization. A factor in the success of such an approach is the careful screening and selection of employees in Japanese firms -- even unskilled, entry-level workers. Moreover, transfers of blue collar employees from job to job within the organization are common -- a practice facilitated by enterprise unions organized on a company-wide rather than craft basis. Newly hired workers, or those transferred to an unfamiliar job, typically pass through training programs considerably more extensive than in the United States.

An apparent paradox has thus developed in the wake of the postwar history of quality control activities in Japan. Many of the original ideas imported from the United States were concerned with statistical quality control, a subject on which visiting experts like Deming and Juran were authorities. Yet there is little evidence that the application of statistical techniques to quality or reliability is any further advanced in Japan than elsewhere. In fact, applications of statistics are seldom mentioned in descriptions of the quality control procedures of Japanese companies. Rather, the Japanese appear to have focused on what might be most simply described as consciousness-raising -- i.e., on making as many employees as possible aware of and committed to the achievement of quality. That this is possible is one indication of real differences between Japanese and Western organizations. Statistical quality control is no more than a small part of the quality programs of typical Japanese hard-goods manufacturers, which the firms themselves often refer to as "company-wide quality control."

Of course, attention to the human factor in quality is not the only possible path to improvement: automating the production process often reduces variability in the controlled parameters, giving better quality and perhaps also better reliability. Most of the applications of automation by U.S. firms in industries like electronics appear to have been driven rather directly by manufacturing costs. While costs are certainly at the top of the list in Japan as well, non-cost factors have perhaps weighed relatively more heavily. Industry in Japan has at times faced labor shortages; in addition, Japanese firms may sometimes have been motivated by the potential quality and reliability improvements to automate earlier than American manufacturers.[17]

CONCLUSION

If the discussion above seems abstract there are good reasons: management functions and their many direct and indirect effects on productivity, manufacturing efficiency, and quality are still largely a black box. Management styles come in many varieties; there are mutiple paths between the inputs to the manufacturing process and the quantifiable outputs. Different firms in various parts of the world develop their own approaches to these problems -- indeed, their own corporate cultures. Nonetheless, internationally competitive organizations show a good deal of similarity in their emphasis on the development of human capital and on their commitments to employee participation programs giving real responsibilities to the work force. At least some of these similarities hold among successful firms regardless of whether their headquarters are in the United States, Western Europe, or Japan -- or for that matter in Korea or Taiwan.

ACKNOWLEDGEMENT

This paper has benefited in many ways from the work of Martha Caldwell Harris, of the staff of the Office of Technology Assessment, and Robert R. Miller, of the University of Houston.

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9. See, in particular, J.M. Juran, F.M. Gryna, Jr., and R.S. Bingham, Jr., eds., Quality Control Handbook, 3rd edition (New York: McGraw-Hill, 1974), Sec. 48 on "Quality Control and the National Culture," which points out that the sharp divisions of responsibility typical of larger organizations in the United States --e.g., separate departments for quality control or inspection -- create reservoirs of specialized expertise, but at the same time may hinder the widespread application of this expertise.

10. A.D. Chandler, Jr. and H. Daems, Managerial Hierarchies: Comparative Perspectives on the Rise of the Modern Industrial Enterprise (Cambridge, MA: Harvard University Press, 1980).

11. For typical examples of this criticism, see the following pair of articles in the July-August 1981 issue of the Harvard Business Review: R.H. Hayes, "Why Japanese Factories Work," p. 56; and S.C. Wheelwright, "Japan -- Where Operations Really are Strategic," p. 67.

12. A host of practical examples taken from fabricated metal products can be found in volumes such as Failure Analysis and Prevention, Metals Handbook, Vol. 10, Eighth Edition (Metals Park, Ohio: American Society for Metals, 1975).

13. See, for example, the comments on production engineering in West Germany in Engineering Our Future: Report of the Committee of Inquiry into the Engineering Profession (London: Her Majesty's Stationery Office, January 1980), p. 224.

14. One commentator claims to know of no case in which the board of directors of an American firm includes the head of quality control, while pointing out that this is not uncommon in Japan. See "Statement of Dr. Thomas Drees, President and Vice President (sic), Alpha Therapeutics Corp., and Member, Board of Directors, Green Cross Corp. of Japan," Quality of Production and Improvement in the Workplace, hearing, Subcommittee on Trade, Committee on Ways and Means, House of Representatives, San Diego, October 4, 1980, p. 58. As a further example, the president of Matsushita, Japan's largest consumer electronics firm, reportedly began his career as a quality control engineer; in the United States, quality control is basically a dead-end job.

15. J.M. Juran, "Japanese and Western Quality -- A Contrast," Quality Progress, December 1978, p. 10.

16. R.J. Barra, Manager of Corporate Product Integrity for Westinghouse, has said, "I come from a background of being in quality for some 25 years, so I know the relationships I've had with engineering managers and purchasing managers and manufacturing managers. I've been the bad boy because I've been demanding quality and they've been telling me I've been holding it up because my inspectors and my engineers have not been accepting the product and letting it get shipped on time." See, "Proceedings of a Roundtable Discussion on Product Quality --Japan vs. the United States, Tuesday, August 19, 1980," U.S. General Accounting Office, June 22, 1981, p. 33.

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INTEGRATED DESIGN AND PRODUCTION SYSTEMS FOR STRATEGIC PRODUCTION

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INTRODUCTION

The theme of the conference is how to increase the Productivity of Production systems by application of Integrated Production System concepts. The control of the system at several levels is especially important in this.

Manufacturing has entered a new age worldwide. The major technical force in this is the recognition that data is a key resource and that manufacturing is a continuum from product design concept to field experience and not a series of separate organizations linked together. The word "integration" when applied to manufacturing implies a true marriage of design and production and that all the levels and elements of the total organization have carried out their roles in an effective manner. While parts of the total organization are diverse the common data running through the entire system is geometry.

While computers, numerically controlled machines, robots and data systems architecture are some of the new powerful tools that can substantially raise product quality and productivity there is a combination of worldwide forces that has produced challenges of major proportions. These are:

A demographic wave of people in underdeveloped countries, growing concern over energy and strategic material sources, more well educated people in the developed countries and a worldwide awareness of large disparities in the quality of living. (Thomson)[1]

A DEMOGRAPHIC TIDAL WAVE

	1975 POPULATION	% URBAN	% UNDER 15 YRS OLD
LATIN AMERICA (ex. Argentina)	322.6	70	45
ARGENTINA	25	80	29
ASIA (ex. Japan)	2,395.5	6-36	44
JAPAN	111.9	75	24
AFRICA	420.1	25	44
EUROPE (ex. USSR)	474.2	67	26
USSR	254.3	60	29
USA	219.7	76	27

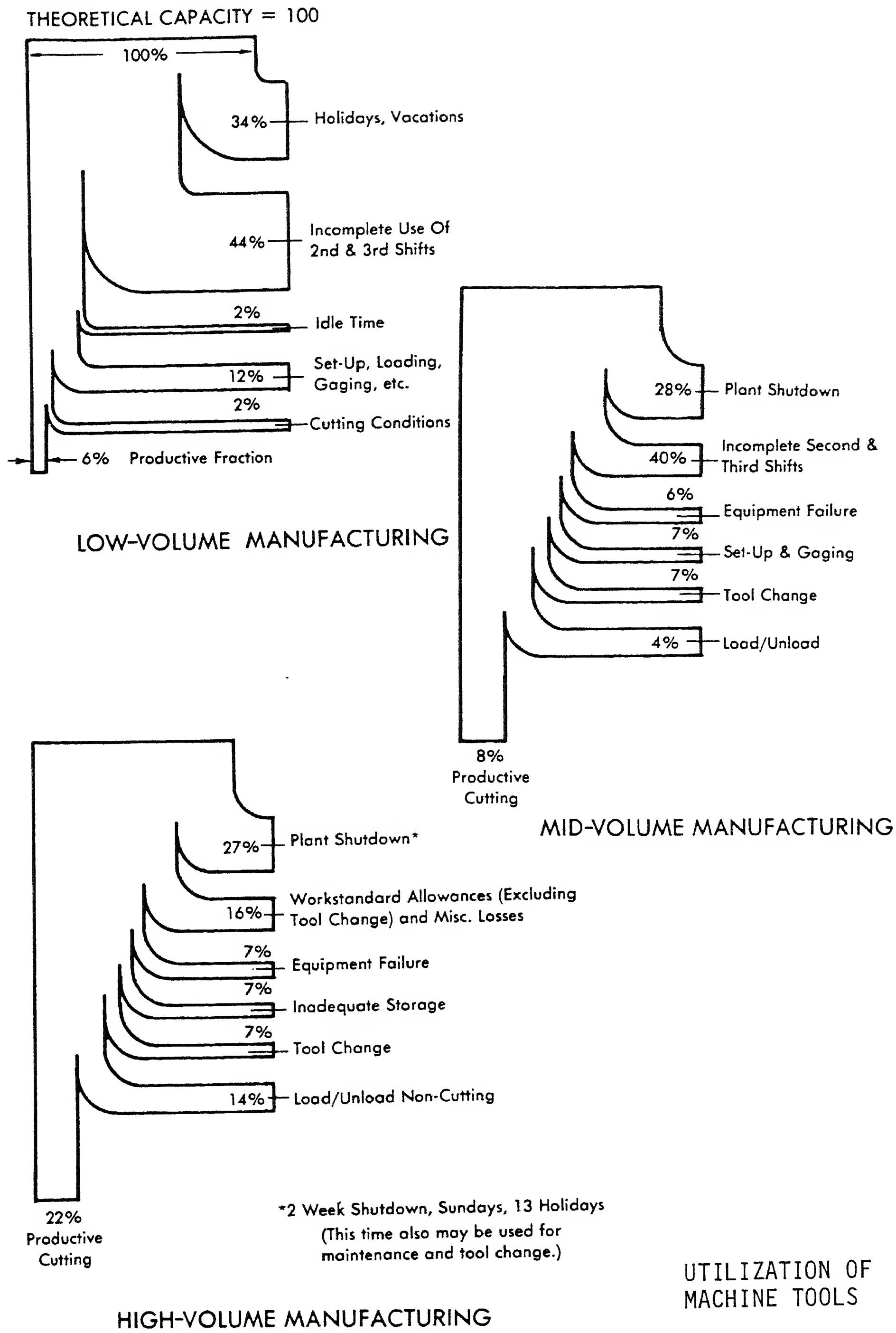
SOURCE:

U.N. STATISTICAL HANDBOOK

The populations of Europe, North America and Japan have been stable since about 1955 but the developing nations show a great wave of young people just coming into the job market. These same countries hold many of the strategic fuels and metals needed by the more developed countries.

There is a high awareness that industrial management practices once thought effective have been shown to be wrong, have led to overemphasis on financial controls, insufficient emphasis on understanding how industrial businesses really function and inefficient use of new technology. (Hayes and Abernathy)[2]

Three important symptoms of management and technical problems are inability to control price, quality and delivery in the face of continuous change, a large amount of work in process inventory and low proportion of total time spent in material processing by capital equipment. An international task force reviewed the technology and use of metal cutting machines. This task force was sponsored by the United States Air Force who had become concerned about the state of knowledge and use of machine tools. (MTTF)[3] Typical utilization values are shown in the next figure. Of course there are a few plants doing much better than shown here but these are representative and show the great investment in process equipment is badly underutilized. The charts show most of the poor utilization is the fault of management. The degree of improvement can also be estimated from the charts.



UTILIZATION OF
MACHINE TOOLS

TRADITIONAL CONTROL OF PRODUCTION SYSTEMS

Management, especially engineering management, is the interactive control of people, technology, machines and money. Control of a system implies management against a set of goals or objectives. Management is often seen as unscientific and science in essence is not managerial. However, there is an overlap where managers can use science to assist and this is where computers and other hardware devices, combined with plans, data, algorithms or other software plus an overall scheme or architecture of communication can be used to improve product quality, productivity and flexibility.

From an overall viewpoint the operation of an industrial operation can be seen below and we can draw some conclusions on the nature of the effectiveness of present control systems. (Thomson)[3] Figure 1 shows that as a new product moves from concept to service in the field, financial risk and the number of decision making people rise to peaks and then taper off. The consequences of good decisions, not requiring redesign, retest or recall produce the greatest benefits early in the product life cycle. The consequences of poor decisions, requiring design changes, hardware modification, retrofit, retest, etc. rise sharply as time goes by. If errors are not corrected in a timely manner, the product may have to be withdrawn from the marketplace.

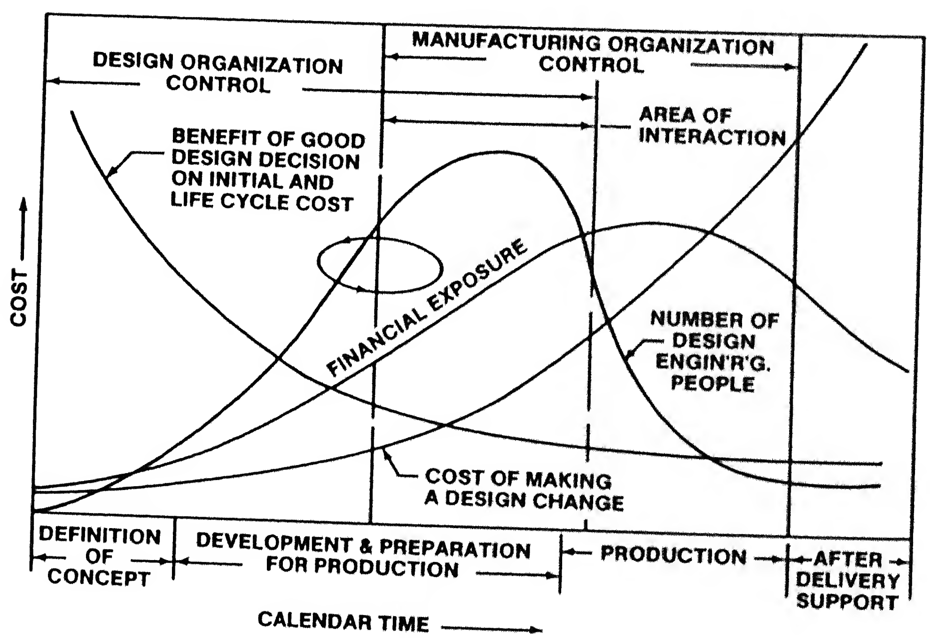
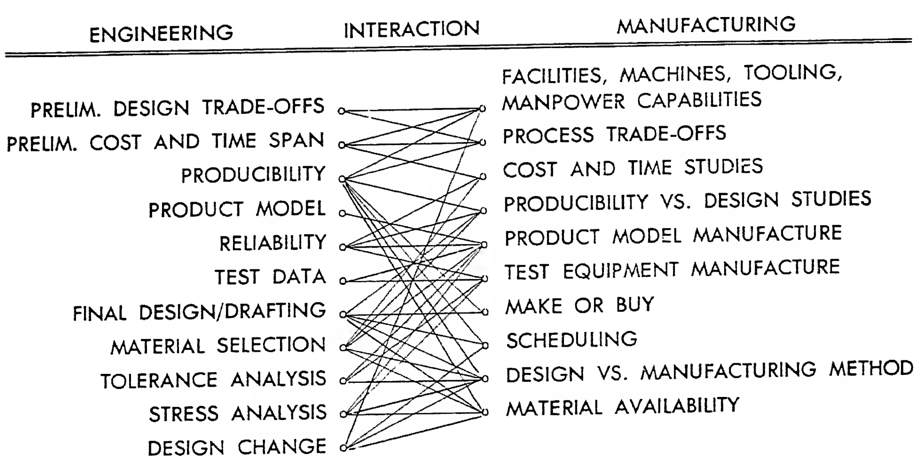


Figure 2 shows the great amount of communication required between only the product engineering and manufacturing organizations. The situation is much more complex when financial, legal, procurement and upper management (plant management and above) are considered. It is little wonder that traditional control systems are a formal system plus an ad hoc, highly human oriented system. It's the interaction of changes or variations that influence the production system from outside, plus the myriad variations from inside, that cause loss of control. Symptoms of these difficulties are failure to meet schedule, excessive cost, excessive lead time, personnel problems, product performance failure and high work in process.

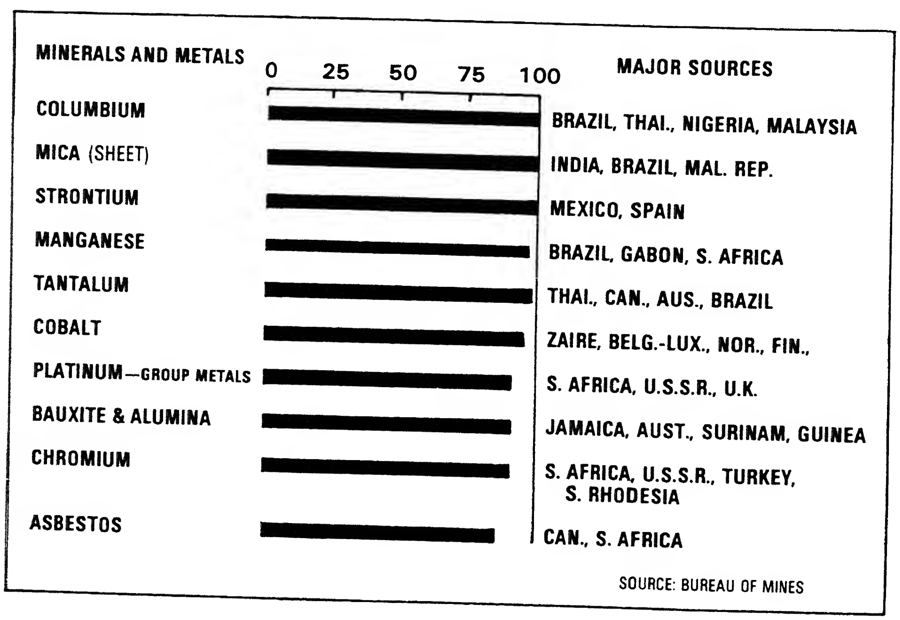
The traditional control system at every level -- process station, department, major program, plant and overall company level -- lacks ability to accept variety and timely feedback of results. Moreover, the diverse organizations do not have consistent objectives nor do they communicate accurately. Some organizations deal in geometric measurements, others in location of goods, time schedules, costs or performance measurements or contractual language. We deal in point to point data, and the result is ad hoc control.



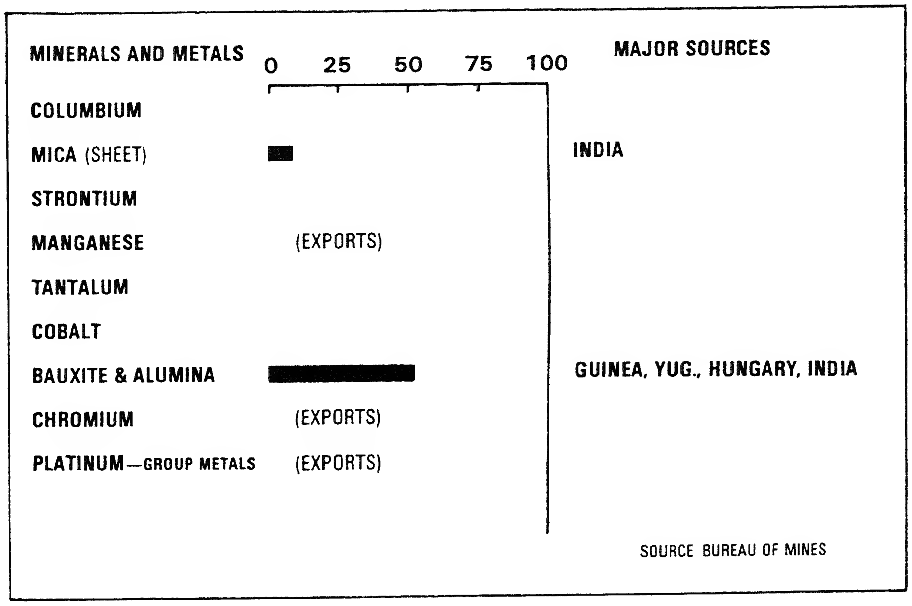
Communication Between Design And Manufacturing

Traditional management control must give way to substantial change in order to effectively gain much more product quality, productivity of the total organization and reduced financial cost and time schedule. This must be done in the face of a large acceleration of change of many kinds from the outside world. These outside changes will come from factors outside control of the production organizations and even nations. Examples are population growth, he location of strategic materials and the numbers of educated or illiterate people and of course, the opportunities and pitfalls offered by the sciences.

A specific example concerning strategic materials is that the major sources of about twenty elements are Soviet Siberia or the underdeveloped (and relatively unstable) countries of Africa and South America. (Dallas)[4] The Soviet strategy of Leonid Breznev quoted in the U.S. Air Force Executive Report is "Our aim is to gain control of the two great treasure houses on which the west depends: the energy treasure house of the Persian Gulf and the mineral treasure house of Central and Southern Africa". (Dallas)[5] Ibid. There are about 1100 lbs. of cobalt alone in the F100 turbojet engine and most high temperature equipment as well as cutting tools depend on this material.



Critical Materials Imports In The USA.



Critical Materials Imports In The Soviet Union

It's clear that we will have a large proliferation of new events plus all the variations in process performance, people performance, poor communication, etc. that we have had to act on in increasing degree since the industrial revolution began -- or rather we should say industrial evolution -- for the world does not change by revolution. A review of any apparently sudden event shows there had been precursors and signs of what could come for some time before. It's the uncertainties of these interactions that we have not been able to cope with in production operations, governments and in all kinds of complex systems. In the case of production systems a new awareness that data is a continuum from concept to field experience offers new opportunity to control. For the material we process in manufacturing is really secondary to the data we process. This data is the basis of all decision making and is the key to integration -- not mere linking of all parts of the production organization, but consistent understanding and timely support to good decisions throughout the organization.

At the same time the value of integration was recognized a more general recognition of social change in manufacturing also became clear from the success of the best plants worldwide. (Thomson)[6]Ibid. These social changes are mutual ownership of change and methods between the workforce and management and the recognition that integrated organizations lead to high product quality and high productivity. The concept of a plant with no

rejectable material at any stage of manufacture is being seriously considered in industry. This concept leads to a disciplined plan to greatly reduced work in process that results in large reductions in lead time and smaller plants. This concept also creates jobs more consistent with the higher education levels found in the developed countries. These events have set the stage for the door to be opened to control systems that can deal with the many varieties of change. However, to succeed in developing such control systems requires borrowing the holistic self-healing or self-regulating concepts found in the complex systems of nature, especially the human body. (Beer)[6,7]. We must take this approach and not see the opportunity as many do by reducing the system to its many elements. Within each element algorithms or descriptions of precisely how to optimize each element are developed and the elements linked or integrated in some fashion. Automation and especially computers make this approach appear enticing, but it is a trap. Real systems of the size and complexity of even a small plant are not understood well enough at any given moment let alone over a time when many variables are interacting dynamically. A very different approach is required.

CONTROL SYSTEMS THAT DEAL WITH VARIETY OF CHANGE

The description of the present control systems have, I hope, shown it is virtually impossible to try to control a complex system under the interactions of many changes by complete understanding of the details. The characteristics of control systems that handle dynamic change and takes advantage of the best human traits, plus the new wave of technologies would be as follows:

The system recognizes a variety of inputs and future uncertainty of a best solution to present conditions.

The system is self-healing and uses redundancy for reliability.

The control system is holistic; that is it recognizes what the normal characteristics should be regardless of change of input or interaction and adjusts the total system within limits to maintain the desired characteristics.

The system recognizes the value of sensors and data and uses the data to maintain near optimum values with allowable structured variations of the normal system characteristics.

The control system is consistent with and reduces mismatch between top management objectives in terms of product quality, capital equipment usage, work in process, product lead or delivery time, costs and balanced obligations to the workforce, government community, stockholders and customers.

A variety of events is controlled by a variety of controls for simplicity, reliability, speed and cost.

The control system utilizes sensor-based inputs and feedback plus a set of instructions for searching according to specified criteria. (A heuristic or searching approach rather than a precise algorithm or differential equation.)

People act as managers throughout, even over processing equipment and are highly trained to recognize symptoms of abnormality as well as normal operation. They have authority to override the local system if required to meet the overall plant goals. People are separated from machines.

The system incorporates Group Technology, Computer-Based Process Planning, Geometric Modeling of physical part descriptions, and "smart machines" for highly productive processing of material, to provide structured artificial intelligence, and integrate product design with manufacturing. There is little or no "learning curve" in the introduction of new products or small lot size.

The system uses "on-machine" sensing for establishing high product quality rather than relying only on statistical sampling. The plant goal is to produce no scrap material at any point. (Machine Tool Task Force Report)[8]Ibid, and (Simpson, et all)[9].

The system uses interactive scheduling to control work flow.

Where computers are used they are linked in a hierarchial manner. Control is localized consistent with a holistic, self-regulating or self-organizing way.

Process machines themselves must change automatically to handle some variations. Equipment must be highly reliable and very well maintained.

RESEARCH RECOMMENDATIONS

There is high interest in Direct Numerical Control, Flexible Manufacturing Systems and Computer Integrated Design and Manufacturing Systems as well as group technology, material processing automation and sensor based local controls for processing and inspection.

Virtually all Western nations, Japan and the Eastern Block nations have national programs. They are aimed at establishing feasibility and educating engineers and management through consortiums of industrial companies and universities. While the major national programs are aimed at strengthening each country's own industry, some technology migrates between nations. Also,

there is strong interest in standards where software and hardware packages link.

For NATO purposes, it's recommended that the programs of the various countries be followed and that a specific international program be implemented for the purpose of establishing the feasibility of a system for producing strategic and critical spares for military equipment. In peacetime, it is not likely that common designs or equipment will be produced. Each NATO country seems to heavily emphasize the development of its own industry for economic reasons. However, there are common concerns in the areas of technology and management and these should be studied together.

The research would be based on:

1. Use of group technology to establish whether part families exist of critical military spares. These might be the structural torque boxes and engine inlets of fighter aircraft, stable platforms, certain electronic components or assemblies and mechanical parts subject to combinations of high load, relative motion between adjacent parts and high heat or corrosive environment.

2. Defining the production system processes and equipment arrangements to produce a selected group(s) of spares.

3. Using miniature physical models and small computers study the most feasible control system/arrangement combinations.

4. Using the holistic control philosophy study man/machine and heuristic control capability against simulated variations of many kinds. Emphasis would be to understand the searching approach.

The research could be carried out by a consortium of universities under the sponsorship and guidance of NATO and the appropriate military service and industry of the country where each university is located. This would be a unique arrangement with benefits of building a base of understanding and working arrangements for future work, long lasting benefits of strong technical ties, faster implementation of new science and shared knowledge in teaching manufacturing engineers at the university level.

Dissemination of the information gained could be accomplished through a NATO Secretariat and the appropriate military service of each NATO country. The universities themselves would disseminate the learning internally through their students who go into industry.

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PROBLEMS IN FORMALIZING PRODUCTION PLANNING IN A THRESHOLD COUNTRY

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INTRODUCTION

Exhibit 1 gives the base for treating the subject in this paper: Problems in setting up a formal production planning and control (PPC) system in a 'threshold' country originate both in the firm itself, in which the system is to be installed, and in its environment. In the sequel, these problems will be taken up in this sequence (internal/external origin), subdividing as in Exhibit 1.

A note on the term 'threshold' country: It is used to denote a country which, although not at the level of the advanced industrial countries of Western Europe and North America, is no more at the level of those usually termed 'developing'. The author's experience comes mainly from his own country, Greece. However, through many contacts with colleagues from other, similar countries, he has formed the conviction that the problems encountered in all of these countries are very similar and that, thus, his generalizations are valid --cf. Pappas (1981).

INTERNAL CAUSES

A production planning and control system overlaps with at least three of the main functions of the firm: Marketing, Production, and Finance. Let us look at particularities in each of these that cause problems in installing a formal PPC system.

Marketing

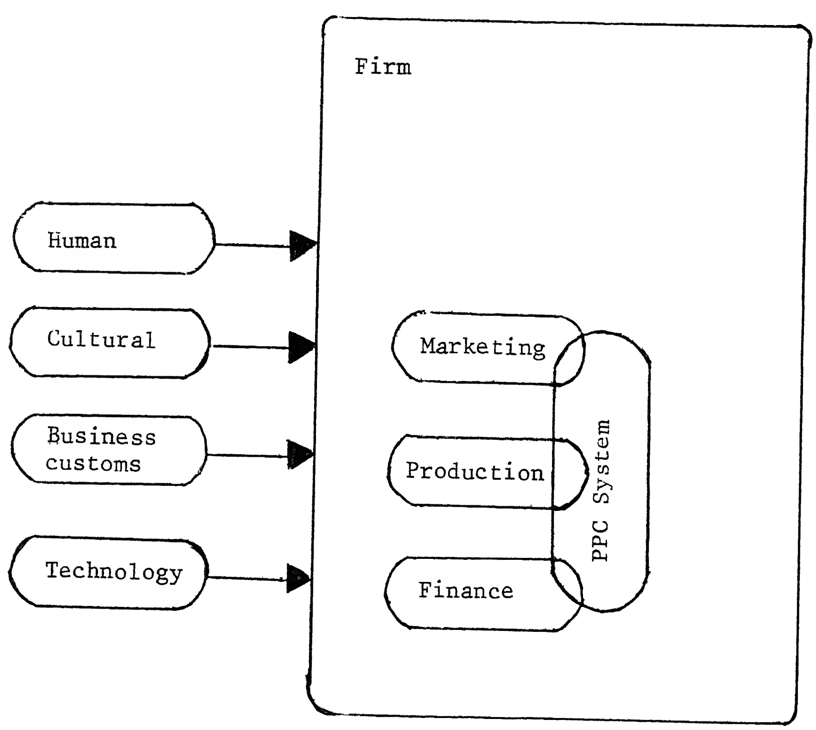
Markets tend to develop and shift rapidly. This creates a

dearth of historical data, on which to base forecasts. It often requires also re-thinking of the basic concepts of the system, eg:

- A traditional foundry and mechanical workshop turns, within a very few years, into a heavy boiler-maker.
- A concrete prefabricator has a constantly shifting mix of small orders from individual home builders and large orders from the School Buildings Authority.
- A metal furniture manufacturer has well-established standard product lines but still accepts customized orders.

Sources of PPC problems

Exhibit 1



Production

Plants have often developed very quickly and haphazardly. The artisan stage is not very far back. Consequently, conventional paperwork is not yet established (no, or only rudimentary, bills of material, routing sheets, etc.) eg:

- A successful home appliance manufacturer had, until rather recently, no bills of material; only a large 'gozinto' chart pinned up on the wall of the PPC office; changes were simply pencilled on the chart.

Thus, installing of a PPC system in such a firm means that the necessary data base has first to be created; a costly process with no immediate benefit.

The rapid evolution in the labour market in threshold countries also plays an important role. Management was accustomed to greater flexibility in the manning of prodction (eg. overtime, second shift, etc.). This flexibility is very rapidly disappearing under the pressures of both, the labour market and restrictive legislation.

Finance

The installation of a PPC system is costly. Some of the benefits it will bring are tangible and can be reckoned in monetary terms. Many, however, are intangible and not obvious to the not educated manager. This entails some reluctance to spend the money necessary. Especially as the sums spent are considered by the accounting system as expenses and not as investment. (See also "Business incentives and customs" in next section.)

EXTERNAL CAUSES

Another group of problems encountered in the installation of a PPC system in a threshold country have their source in the environment in which the firm operates. These stem mainly from human and cultural characteristics of threshold countries. The availability of equipment and software is also an important problem.

Human

In all threshold countries the author has knowledge of, there is an acute lack of the skills necessary for the setting up of a PPC system.

- A plant manager in a large provincial city: "You can find nothing between the levels of unskilled worker and Diploma-Engineer: no time study specialist, no preparation-of-work technician, no lower-level engineers".

To this remark must be added that even Diploma-level engineers with a specific training in PPC are scarce (Turkey being, perhaps, an exception in this respect).

This lack of skilled personnel can be remedied only in part by training abroad in the developed countries. Those who return from such training find it difficult to put their ideas through at their jobs.

Literacy can also be a problem, in case of involvement of personnel with lower skills, say in a plant data collection system. Schooling in threshold countries tends to be ineffective, so that, although most can read instructions, many lower-skill workers (and often not only those) have trouble writing and filling forms.

Cultural

Planning, of any sort, is not a very well-established concept in developing societies and is still new in threshold countries. This may be ultimately due to climatic conditions, or it may just be one expression of the cultural syndrome of not yet being 'developed'. In any case, it is not traditionally encouraged. Schools give praise for improvisation, for bright ideas; rarely for well-planned, continuous effort. Thus, the setting up of a PPC system in a threshold country requires an extra 'selling' effort within the firm.

Language can also cause problems. In 'developing' countries the problem is not so acute, because, in these, the use of English or another language with a well-established terminology is the rule. Threshold countries however tend to favour their own national languages. The case of Greece is probably the most difficult.

- Habit requires the use of Greek terms; however, very few are established; so they must be created; however, foreign terms can seldom be taken over, owing to the structure of the language and its lack of affinity with others (unlike, the latin and, to a lesser extent, all West-European languages, where terms can be borrowed by merely changing an ending); and even the alphabet is different!

Business incentives and customs

The production function tends to rank low among the concerns of managers and enterpreneurs. The reasons are many:

- Many industrial enterprises have developed from former commercial firms; they tend to be sales-driven rather than production-driven.

- Finance is, especially nowadays, the crucial management concern, owing to the inefficiency of capital markets and the resulting high degree of borrowing. This borrowing comes usually from the money market tightly controlled by the government, so that the concern about finance has little to do with efficiency of the firm but, rather, with meeting (or circumventing) bureaucratic criteria (eg. credit line set at a rigid percentage of fixed assets).

- Almost of equal importance is managerial concern with endless government formalities (import quotas, export subsidies, asset assessment, hiring and firing restrictions, a.i.). This is especially tedious, because regulations are constantly changing.

For all these reasons, the installation of a PPC system does not receive the backing and involvement of top management that it deserves.

Technology

The PPC technology is not so easily obtained in threshold countries as it is in developed ones. By 'technology' here is meant not only equipment (computers) but also appropriate software and know-how. Equipment costs twice as much as in the United States, if not more. Software cannot easily be bought from a great distance -- and is often inappropriate, given the particularities mentioned in the section 'Internal causes'. As to know-how, the scarcity of trained personnel was already mentioned; to this must be added the lack of local consulting firms and the high expense and difficulty in using consultants from other countries.

SOME SUCCESSFUL CASES

In spite of all the problems described in the preceding sections, there do exist successful PPC applications. Exhibit 2 lists a number of cases the author is acquainted with. They cover a wide range of applications, but some types of applications are more frequently encountered than others; Exhibit 3 is an attempt to indicate in what type of firm are PPC applications most likely to be found.

The following points are, in the author's view, very good advice for successful PPC applications; they sum up the experience of a large textile firm that has already a number of successful applications:

- Use bottom-up approach: start from low-level applications; link them together, when they have been successfully implemented, by higher-level applications.

Some successful PPC applications

Exhibit 2

Company	Type of application
Pharmaceutical packaging/ multinational	Job shop loading and control/ /ready-made commercially available software package no previous system
Pharmaceutical packaging/ local	Job shop loading and control/ /manual system developed over many years with help from foreign consultants/electronic system planned
Aeroplane servicing	Job shop loading and control/ /commercially available software package with extensive adaptations/not yet fully operational
Motor car assembly/ Japanese licence	Well-developed hierarchical production planning/manual/ help from licensor
Home appliance manufacturer/ local	Various successful ad hoc applications/commercially available software package for inventory control
Lorry manufacturer/ foreign management	Data collection system and manufacturing order control system/conventional/taken over from Central Europe
Cement plant	Full automation of plant operation
Large textile manufacturer	Fully automated loom monitoring system/in operation/ some help from foreign consultants
Large textile manufacturer	Computer-based order scheduling system/help from from foreign consultants

Likelihood of Occurrence of formal PPC system

Exhibit 3

Attribute of firm	Likelihood of occurrence	
	More likely	Less likely
Size	large	small
Market	export	local
Ownership	private	government
Production process	flow shop	job shop
Branch (product)	metal-working	non-metal-working
Nationality	multi	national
Type of system	simple, tactical	integrated

- However: Develop early a concept of how the various applications will be linked together. Develop individual applications with this overall concept in mind, reviewing it when necessary.
- Do not attack on many fronts at once: start with only a few problems; success breeds rapidly time will be gained later, when applications will snowball as soon as the first applications will have yielded their results.
- In case of choice between departments in which a particular application is to be studied and implemented first, select the one where the problem appears in its more general form; other applications will then be mere specializations of the first one.
- Last, but most important: Secure top management backing and middle and lower-level management involvement from the beginning through all phases of development of the implementation.

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A SYSTEMS APPROACH USED IN DEFINING HIGHER MANAGEMENT INFORMATION NEEDS IN A MANUFACTURING COMPANY: PRINCIPLES AND METHODOLOGY

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INTRODUCTION

This paper presents an interim report on thinking underlying the work of an ongoing project being carried out by the Department of Systems of the University of Lancaster. The project concerns a large manufacturing company, one of the major in its field. The current economic situation is forcing the company to obtain the most from resources. In order to remain competitive, productivity has to be improved in all areas, not just direct labour. This requires professionals at all levels to work more effectively with better quality information, rapid access to information, and information which they can trust. The level with which this work deals is the higher management level and the problem: its information needs.

The extensive use of high-speed computers in data processing has theoretically provided the operating manager with a powerful tool to help him in his decision-making process. The simple increase, however, in the quantity of data generated and the speed of the transmission does not necessarily lead to more informed decisions.

The assumption that the more data available to the decision-maker, the better must the decision be reached has proved to be erroneous and sometimes even dangerous by leading many a decision-maker down the path of confusion. Even the continuous updating of information and the graphical and visual display of relevant data will not of themselves lead to better decisions.

What is needed is an understanding of the type of information

actually required by the decision-maker at his own particular organisational level and environment.

While increasing amounts of information can considerably aid middle managers in taking decisions, the top echelon must still rely on intuitive judgement. Often the data collected and analysed by the computer is of little value to higher management precisely because these decisions do not rely solely or even mainly on the fund of computer-generated data but rather are based on historical data in the budgetary sense (long range planning as to products, competition, customers, service areas and the like).

One can readily understand how the premise "the more data the better the decision" may have come into vogue. Since the use of costly computers, which is currently the fad, must somehow be justified, there is a tendency to have them generate as much data as possible, irrespective of the utility or the cost of the output. It is clear that in this case the computerised data processing systems came to give answers to a lower level of resolution without paying much attention to the existence of a higher level. That is, they tried to deal with how the data should be processed, without questioning what type of data is needed. What underlies this fact is the confusion as to what constitutes information and consequently information systems.

An information system is a set of organised procedures which, when executed, provides information to support decision-making and control in the organisation. Information can be defined as a tangible or intangible entity that serves to reduce uncertainty about some state or event (Bedford, 1966). So it must be distinguished from the concept of data as well as from knowledge. The term data is used to refer to entities that have not been evaluated for their worth in regard to a specified individual in a particular situation. On the other hand, knowledge can be regarded as evaluated data for general future use. In contradistinction, information refers to inferentially intended material evaluated for a particular problem, for a specified individual, at a specific time and for the explicit purpose of achieving a definite goal. In other words information concerns selected data with respect to problem, user, time and place. At this point two concepts emerge that should be of great importance for processing of information valuable to higher management. The concepts are those of filtration and condensation (Ackoff, 1967). Filtration involves evaluation of data as to relevancy, while condensation involves curtailment of redundancy in the mass of otherwise relevant information.

THE CURRENT SITUATION

The (major) current approaches in defining managerial information needs can be classified into four main categories: (Rockart, 1979).

These are the "by-product" technique, the "total study" process, the "null" approach and the "key factor" method.

The By-Product Technique

In this case the organisation's computer-based information process is centred on the development of operational systems that perform the required paperwork processing for the company. The information by-products of these transaction-processing systems are often made available to all interested executives and some of the data are processed to the upper management. The by-products that reach the top are either heavily aggregated or they are exception reports of relevant interest. Or, in the case of many electronically processed data, the reports reaching the top are often typed versions of what a lower level feels is useful or even the result of a previous one-time request for information concerning a particular matter initiated by the chief-executive in the past.

The Total Study Process

The objectives of the process are to develop an overall understanding of the organisation and its functions by querying an extended sample of managers about their total information needs. The results are compared with existing information systems. Then, the sub-systems necessary to provide the information currently unavailable are identified and assigned priorities. The most widely used formal procedure to accomplish the total study is IMB's Business Systems Planning methodology (BSP). BSP is aimed at a top-down analysis of the information needs of an organisation. In a two-phase approach, many managers are interviewed to determine their environment, objectives, key decisions and information needs. Then the results are evaluated through network design methods and presented in an easily visualised manner. New systems are then designed and implemented to fill the observed gaps in the existing ones.

The Null Approach

The philosophy that underlies this method is that the executives' activities are dynamic and ever changing, so one cannot predetermine exactly what information will be needed by him with changing events at any point in time. These executives, therefore, must be dependent on future-oriented, rapidly assembled, subjective and informal information delivered by word of mouth from trusted advisers. The supporters of this approach believe that all computer-based systems - no matter how well developed - are useless. Their belief is partly based on work of a number of management scientists like Henry Mintzberg who believes from emperical studies that analytical inputs (reports, documents, and hard data in general) are of little importance to top echelon management.

Key Factor Method

The two concepts that Ackoff mentioned in his article (Ackoff, 1967), namely that of condensation and that of filtration, are present in this method. The selection of a set of key factors or key values which give an image of what happens in a number of areas within the organisation, provide the necessary information. More detailed accounts are made available to the manager by exception reporting, indicating where actual performance appears significantly different from the expected one.

This method seems to be the "best" among the existing approaches. It provides to higher management indications about the state of the whole organisation and on the other hand it allows focussing only on those areas where performance is significantly different from planned. Yet, this method tends to be financially all-inclusive rather than targetted to a particular executive's specific needs. The information provided is of the hard type, quantifiable and computer-stored. In presenting an extensive information base, it covers partially the executives' information needs, failing to provide more complete assistance.

The total study approach, clearly a reaction to two decades of data processing with relatively little attention to management information needs, tends to be highly useful in cases. But it is very expensive, the huge amount of data collected makes it complicated, and it is oriented towards general action rather than serving individual managers' needs.

The by-product technique, which seems to dominate the current information systems, focuses on inexpensive paperwork processing by cutting clerical costs, but it is far less useful with regard to managerial information needs.

The null approach, although it helps in paying attention to the soft type of data a manager needs to perform his task, underestimates the importance of the periodical reporting and of hard data. Hard data may not be everything the higher management needs, but they certainly constitute an important part of the information that is vital for an organisation.

THE METHODOLOGY USED

The following approach is mainly based on Soft Systems Methodology, developed by Professor Peter Checkland and his colleagues in the Department of Systems at the University of Lancaster (Checkland, 1981).

A model underlies the implementation of every information system, either implicitly or explicitly, and it dictates the logic of the system. The usual case is that these models and consequently the

designed information systems based on them, are oriented towards the operations level aiming at providing large quantities of rapidly processed data. When it comes to the case of higher management, an analogous system is usually implemented, providing the same type of information. The argument that lies behind the proposed approach is that there exists a fundamental difference between an information system designed for the operations level and an information system aiming at providing information in order to support higher management decision-making. The examination of alternative elements and structures in both cases relies on the use of models.

In the case of the operations level where roles and functions are much clearer and better defined, and where automated procedures are being rapidly developed, analytical tools exist in terms of mathematical models and the situation resembles more to that of designed physical systems. Where mathematics has not so far succeeded as a modelling language, is the era of higher management control systems. In this case what has to be modelled is systems of human activities.

A management planning and control system is a human activity system and as such it continuously learns and evolves. It can be analysed and designed in terms of sets of ongoing activities and the structured way in which those activities are related both to each other and to the enduring purpose of the planning and control system (Wilson, 1979). An information system designed to support management's decision-making must entail this principle. Since human judgement and intuition are used to interpret the data provided by an information system, as well as to design the cost-benefit model, an adequate approach must merely provide a rational framework for decision-making. So that the art of decision-making will change from a loosely structured, intuitive mode to one based upon rigorous analysis supported not only by intuition but also by documented research and information. Another point that should be emphasised is the distinction between the 'what' and the 'how' of a situation. If this is done, the approach can be at the level of basic activities and the information flows deriving from them, are thus independent of the means by which data are processed.

Here we come to an essential difference. A manager is free to attribute meaning to human activities; hence to perceive his situation in a way personal to him. This means that the information system designed to support his decision-making must be highly adaptive, but not necessarily to a consistent and unchanging objective function; it must be flexible in order to respond to particular disturbances, it must have sound appreciation of the manager's objectives and it must incorporate the point of view that makes these objectives logically interdependent.

At every period of time there exist certain areas that are of

vital importance for the organisation, and where the organisation's policy must prove to be both efficient and effective. A selected number of objectives is set at any given time by the organisation's management with respect to these areas. It is evident that most organisational efforts are oriented towards the fulfilment of these objectives. This task required that a limited number of activities have to be carried out successfully. These activities are not an account of everything a manager at this level has to do. But they must be carried out satisfactorily if he is to perform his task with success.

The effective execution of each one of these critical activities requires a minimum amount of information. Analytically, if each one of these activities is regarded as a transformation process, it can be seen that it requires specific information as input in order to provide the desired output which can be the input for another or a number of other activities at the same level, or constraints for activities at a lower level, or information for activities at a higher level of the managerial echelon.

The gap between an objective and the actual result provides the difference between desired and actual state which gives the measure of performance for the corresponding activities, and leads to corrective action.

At this point the steps of the approach are clearly defined. Firstly, the objectives of the management are defined, with respect to the areas of vital importance for the organisation, incorporating the particular viewpoint of the manager who is responsible for their fulfilment. This is done in close co-operation with each manager in each case and is maybe the most crucial part of the approach.

In the second step a conceptual model of the human activity system is formulated. This activity system is modelled as a transformation process. The boundary of this system contains the minimum, necessary set of critical activities (at a particular level of detail) required to carry out the transformation.

Once the conceptual model has been formulated, then following again the transformation process the information which is required as input by the critical activities can be defined.

Where hard data are perceived to be available they are included in the information system after being modified in the desired form. Where softer types of information are necessary, the type of information needed and the difficulty and/or cost of acquiring it must be carefully examined. A measure must be established for each set of critical activities, so that at any moment the existing state of the system can be examined. These measures will indicate the current state in the particular area of interest. They may consist of either

hard type data or verbal statements, whichever is judged to be necessary. In the area of Production Planning and Control, for instance, the Capacity Planning function is one of vital importance. For this function, its main objectives may be to:

- Minimise production delays due to conflicting resource requirements.
- Meet production needs by projecting the capability of the manufacturing facility.
- Increase plant efficiency by providing production management with an effective planning tool.

To achieve these objectives the following types of critical activities have to be carried out:

- Provide adequate reporting to allow the production manager to make sound decisions to adjust load or capacity.
- Provide an analysis of planned utilisation.
- Analyse current and future production levels in each work centre in order to identify potential resource shortages.
- Provide a planning tool for effective utilisation of production facilities.

Sufficient support is provided for each one of these activities in terms of information by the reporting features of the system. The type of information necessary for the higher management can be provided by establishing two measures: the capacity plan factor (measured as load from master schedule versus manpower and machine capacity by work centre per week) and the input performance factor (measured as standard hours content of released orders versus capacity plan). In other areas where things are not so well structured, important activities like "appreciate organisation morale" could be measured by establishing factors like "absenteeism", etc.

In the specific case where this approach was applied, it was found useful to integrate the higher management information system with the formal operations level information system. In this way, the same sources of data would be used and that would ensure a better performance of the higher management information system.

So far we have been referring to higher management information needs that lie at the conceptual level of 'what'. The level of 'how' is the next step that has to be taken. There is a new technology evolving in the area of data processing and communications. Its main characteristics are:

a. its low cost,

b. the fact that it is interactive,

c. it is distributed.

Given that, then the methodology presented could become the link between the levels of 'what' and 'how', namely the higher management information needs and advanced information technology. A well-structured extensive data base could be used for every type of data that could be stored and processed by computer. This information could be distributed through interactive computer terminals.

The main efforts should be concentrated to the structure of data that should be included in that data base. It is clear that a special subsystem must be developed, serving the higher management information needs, different from the information system that supports the operational level. Whenever desired information cannot be stored and processed by computer, additional reports can be produced.

Both the computerised part of the reports are parts of the formal information system that must be established to satisfy higher management information needs.

ACKNOWLEDGMENTS

I would like to thank Professor P. B. Checkland and Dr. B. Wilson, members of the Department of Systems at the University of Lancaster, for reading and commenting on this paper and also Mr. R. H. Anderton, Head of the Department, with whom I worked fruitfully during the project period.

Finally, I should mention the contribution of Professor I. A. Pappas, who being both my teacher at the National Technical University in Athens and personal advisor, held a major role in helping me follow this intellectually challenging path.

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MANUFACTURING SYSTEMS RESEARCH:

IMPRESSIONS OF A RESEARCH PROGRAMME

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INTRODUCTION

This paper describes a research programme sponsored by the Science and Engineering Research Council. The programme examines manufacturing as a systems concept. The objective is to find ways of improving manufacturing efficiency and customer service through better organisation of production. New production technology often provides the stimulus to examine the control system; but this research is also concerned with the better co-ordination of existing production.

The research methods are still evolving. The different approaches used amongst the thirty or so projects in the programme are discussed. Some general conclusions from the research results of the programme as a whole are inferred, and suggestions on future research needed are made.

The author expresses thanks to the Science and Engineering Research Council for the information on the research. The opinions expressed here are those of the author.

THE DEFINITION OF THE PROGRAMME

Origins

This programme is descended from two previous SERC initiatives in the field of production co-ordination. The first, "Efficency of Batch Manufacture", emphasised the need to understand current practices in industry. One tenet was that established practice was instinctively often successful in co-ordinating different subsystems

without explicitly recognising how. The aim was to develop general principles for identifying and defining the interactions in the total system. A model project of this type is the research by Gomersall (1) into how the amount of visible backlog can influence rate of production.

The second initiative, "Integrated Production Systems", aimed at examining how to apply control engineering principles beyond the physical connections between processes. One aim was to classify how flows of information and the design of the information system differ from physical flows and systems. Information systems are so flexible that they are immediately affected by changes in the objectives of the people using them. A methodology for understanding them was proposed. The aims of both initatives were broadly similar, and they have been combined into the programme "Efficiency of Production Systems", which is the subject of this paper.

Scope

Manufacturing systems transform inputs in the form of labour, materials, energy and capital resources into marketable outputs. They encompass the equipment, its layout and relationship to the products produced; the work practices; the planning and control routines; the order generation methods; and the interfaces with marketing, sales, design and finance. The aim of an integrated manufacturing system is to coordinate all these subsystems. This can only be achieved through information flows and decision making processes which must also be regarded as part of the manufacturing system.

In practice few research projects have the opportunity to carry out studies on such a broad front. Most projects have concentrated on understanding the information requirements of a single subsystem, with a view to examining how these can be integrated with a second subsystem. Some examples are progress monitoring and quality control inspection; progress monitoring and production planning; product design and process planning.

The subsystems being examined are process planning; work content estimation; production scheduling; progress monitoring; order generation; maintenance; quality control; production planning; and design for economic manufacture.

Emphasis

Various attempts have been made to provide a more concentrated focus for the research. Three dimensions here are the industries and type of production, the type of research, and the viewpoint taken on system integration.

The programme is concerned with batch production i.e. manufacture of different products sharing processes by a series of operations in discrete batches. The assumption is that increasing competitive pressure will lead to a need for more flexible (in terms of leadtime and product variant), more varied (in term of overall mix), and smaller (in terms of batch size) production. Meeting this need will involve both production technology and its control systems. Most of the existing research is in some part of the engineering industry, but there are projects in the paper, textile and steel industries.

The research involves implementing system improvements within collaborating companies. Although this makes generalisation of results difficult to define, involvement with real data and real system interactions are considered essential. The extent to which formal methodologies can exist, and can produce effective and transferable results, has yet to be established.

The object of integrating the subsystems is not only to use resources better, but also to provide better customer service, (measured in terms of leadtimes, delivery reliability and quality assurance). The latter aim implies better scheduling of material flow from order receipt to product delivery. The viewpoint looks upwards from improved efficiency of a single process towards a group of processes, and ultimately towards the whole site. The programme is concerned with the implementation of an agreed manufacturing strategy in this way rather than choice of strategy.

METHODOLOGY LABELS

This field of research has no traditional academic community and no well established body of knowledge. The reseach programme is being carried out by production engineering, management science, operations management and systems disciplines. The methodologies used have overlapping interests but the root similaries are difficult to discern.

The Systems Approach (Checkland)

The original IPS initiative emphasised "action research". The most accurate of the various definitions of action research used at the time has turned out to be "research within an organisation whose progress is guided by the needs of the organisation". This style has been given a more rigorous format by Checkland (2) on how research should be carried out, but it is not clear if any generic models of production systems can emerge from this process.

The integration of production systems is a sufficiently unstructured problem at present to need research using this approach. Whether this in intrinsically an unstructured subject is not clear. The approach of computer based manufacturing database systems

supporting automation favours a structured manufacturing architecture.

Operations Management

Buffa (3) describes how operations mangement has evolved from the management science and operations research viewpoint towards a focus on management issues and simpler broader based models. The lack of acceptance by managers of complex models (especially those of narrow scope using single-valued criterion) discussed in that paper can be supported by impressions from this programme.

The operations management approach, while broader than management science, does not seem committed to the integration of production subsystems. They have concentrated on the management of aggregates of orders and resources. This perhaps has lead to a preference for investigation of manufacturing strategy and management styles.

Production Engineering

The production engineering approach in contrast has focussed on the process planning and subsequent machine control of individual orders. Integration of the production systems is based on the introduction of new technology. The availability of inexpensive computers has stimulated the integration of computer aided design and manufacture (CAD-CAM). Appleton (4) notes the search for conceptual information structures for manufacturing enterprises which require identification of common company wide data with agreed definitions.

While the production engineer is trying to eliminate human equivocation (or at least contain it through 'expert systems'), and operations management is rediscovering it, the systems approach provides a useful balance. The combination of approaches is valuable.

INTERPRETATION OF RESULTS

Most completed projects have concentrated on understanding particular subsystems and their external connections. The scale of project possible at this stage limits the extent to which practical research can be carried out on the whole system. Results from achieving implementations have been important in focussing attention on some central issues.

Types of data

Some research has used mathematical simulation but the data and decision rules were not always representative of the real situation. Substantial effort has now been devoted to data collection. This has brought out important differences in the characteristics of data used

in organisations. Accounting data is usually formalised and structured, and the emphasis is on accuracy within the definition of the accounting system. Engineering specification data is voluminous, and the extent to which it is available for processing within an information and control system varies widely. Operations management data is time-critical and has less substance (especially that concerned with future actions).

Analysis of the data used in an organisation, and identification of common items and definitions, is proving a useful method of understanding the interactions in a system. The quality, frequency and level of detail of data available is conditioned by the nature of the organisation, and must also be taken into account.

Descriptions, not calculations

Traditionally the development of the computer has encouraged research to focus on the calculation power available. This has assisted the integration of systems where the data has sufficient structure. Operations management applications have often been oversimplified in order to fit them onto the computer. The validity of the results are difficult to prove in practice. There is evidence (5) that the experienced production controller can handle complexity in an uncertain situation more effectively than the computer, by using his knowledge of underlying patterns.

An iterative solution between descriptions of the position and the human decision maker seems required. In work scheduling, for example, a statement of current work at a process, given priorities by the production controller and agreed by the foreman as feasible in terms of capacity available, is more easily actioned. This applies especially where the production processes are not physically integrated, and consequently there is great flexibility. Production control systems in that environment must relate closely to the interests of the people involved. The way they are consulted during the design and introduction of the system is significant (6).

Decision making

Data for coordinating production needs to be aggregated in order to present the implications of the interactions to their managers. Management decisions making, as opposed to technical decision making, depends on the cognitive style of the individual. As the number of factors involved increases, so the objectives become more conflicting. There are many feasible courses of action, and the decision rules can rarely be defined precisely enough to explore all possibilities and determine a single best solution.

Some research in the programme (7) has been examining how to define and agree the appropriate level of detail within an

organisation for displaying the interactions at various levels. A distinction is made between the choice of data items required (frequency of recording, fundamental classifications and coding systems) and the way the data are best aggregated in reports for current decisions. Results indicate that the design of the reports, and to a lesser extent the choice of data items, depend on the circumstances of the organisation. Consequently information systems for planning and controlling production are essentially temporary, unlike the performance recording systems in accounting, and the specifications systems in engineering. This has implications with regard to the design of hierarchial networks of distributed computer system for production control.

IDENTIFYING GAPS

The existence of gaps in this body of knowledge is well known although not often discussed in the literature. Some research has been carried out in these areas within the programme.

Performance Measurement

The measurement of efficiency in terms of the utilisation of men, materials and machines (current profitability) takes no account of customer service and satisfaction (a determinant of future profitability in many businesses). Delivery reliability, leadtime comptetiveness and quality assurance effectiveness are difficult to measure.

Absolute measurement of the overall performance of the manufacturing system usually concentrates on productivity measurement. One project in the programme (8) has developed a framework for evaluating company performance in terms of productivity; and this provides a useful basis for further research.

There are significant practical difficulties in measuring operating performance in detail, even when all operating records are available. The unavoidable outcomes from previous investment and marketing decisions are not easily differentiated from events which were or could have been controlled. There are no measures of the extent to which people have cooperated together. Improved performance on one measure can easily be achieved at the expense of another (often in a different time period) eg. capacity utilisation at the expenses of delivery performance. Suitable units for recording customer service and manufacturing flexibility await discovery.

Coordination complexity

The technology employed, type of manufacturing operations, diversity of products and equipment, market expectations, ease of

material supply and competitive position are all factors which may affect the complexity of the system. The task of coordinating these is examined (9) in terms of the indirect links between a firms environment and strategy and its production control system. The quality identified there as means of assessing the organisational complexity is the toleration of slack in the system. This many provide a useful way forward on performance measurement. Some research (10) has been done within the programme to suggest a list of factors to be used for classifying manufacturing profiles in terms of complexity. The aim there was to see if the profiles could provide a guide to when and how to move to computer based production control systems. Other research in the programme (11) has noted the gulf between the precise specifications of computer package production control systems and lack of definition of how an existing system actually works and can be improved.

Need for standards

The lack of established terminology and standards for describing systems is a barrier inhibiting the generalisation of problem identification and methodologies. New disciplines may emerge to overcome this; alternatively existing disciplines may gradually combine. Within the programme the need for standard terms (12) and conventions for system description (13) are being examined.

CONCLUSIONS

Research into manufacturing systems as a systems concept covers many disciplines.Concentration on implementations is bringing out a better understanding of the nature of the data required for coordinating production. A greater awareness of the relationship between computer systems and human decision making points towards simpler and more descriptive models. The exisiting methodologies for this research do not permit adequate generalisation of the results, and this creates a significant barrier to developing general principles on the organisation of manufacturing systems.

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